PART G - CONSTRUCTION EQUIPMENT

The information in this Part pertains to commonly used construction equipment. Knowledge of the equipment used in construction is necessary for the Inspector to properly perform his or her duties. This knowledge will allow the Inspector to understand what the Contractor is doing at any given time and how the Contractor's work affects the Project. It will also assist the Inspector in assessing whether or not the Contractor is in conformance with the Specifications. Finally, it enables the Inspector to identify potential problems and act to head off problems.

The information provided here is intended solely for the Inspector's information and to aid in the performance of the Inspector's duties. The selection of equipment and methods of construction is left to the Contractor unless otherwise stated in the Specifications.

DIVISION G200 – EARTHWORK EQUIPMENT

SECTION G201 – BULLDOZERS

G201.01 General. The bulldozer is one of the most commonly used pieces of earthmoving equipment. It has a number of applications, from clearing and grubbing to site maintenance. In addition, there are several attachments that increase the versatility of the bulldozer.

A bulldozer is a tractor that has a blade attached to its front. The tractor is mounted on either crawlers or wheels (actually, a wheel-mounted bulldozer is usually just a loader with a bulldozer blade attached, and is know as a Turner Dozer). Bulldozers are commonly classified based on these mountings. Each of these two mountings has advantages. Crawler-mounted bulldozers can offer better traction on soft soil, the ability to travel over a greater variety of surfaces, and more versatility on the Project. Wheel-mounted bulldozers can travel faster, have a higher output when considerable traveling is necessary on the Project, result in less operator fatigue, and can travel over pavements without damaging them.

The blade attached to the front of the bulldozer is used to push soil, debris, or other material. The blade can be lowered and raised, allowing it to excavate and distribute soil. On many bulldozers, the blade can also be angled to the left or the right, so that material is pushed forward and to one side.

The bulldozer is commonly used in excavation and embankment construction, as described in Section 202 of the Specifications and Section G202 of this Manual. The bulldozer can also be used in clearing and grubbing, topsoil removal, and maintenance of haul roads and borrow pits. Figure G-1 shows a typical crawler-mounted bulldozer.

Figure G-1: Crawler-mounted Bulldozer

G201.02 Bulldozer Attachments.

(a) *Rippers:* Rippers, also known as scarifiers, are hydraulically operated devices that consist of one or more shanks, or teeth. Rippers are mounted on the rear of the bulldozer tractor, and are used to break up, and in some cases remove, material from the ground. Rippers can be used to break up soil or to break and remove rocks from the soil. Rippers can also be used to aerate the soil for drying or adding moisture. Figure G-2 shows a typical ripper.

Figure G-2: Crawler-mounted Bulldozer with Ripper Attachment

(b) *Brush Rakes:* Brush rakes are attached to the front of the bulldozer in place of the blade. They serve much the same purpose as a traditional garden rake: they are used to clear vegetation and debris from the soil without removing the topsoil. Figure G-3 shows a typical brush rake.

Figure G-3: Brush Rake Attachment

(c) *U-blade:* A U-blade is sometimes attached a to bulldozer in place of the standard blade. The U-blade gets its name from the fact that when viewed from above it looks like a "U". Because the blade is curved in at both edges, it will lose less soil in front of it than a standard blade will, and will carry the soil for a longer distance. Figure G-4 shows a typical U-blade attached to a bulldozer.

Figure G-4: Crawler-mounted Bulldozer with U-blade

G201.03 Bulldozer Manufacturers. The following is a partial list of companies in the United States that manufacture bulldozers or bulldozer attachments. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	Location	Phone Number
Case	Racine, WI	800-835-2273
Caterpillar	Peoria, IL	309-675-1000
Dresser	Springfield, OH	513-323-4981
John Deere	Moline, IL	609-675-4381
Komatsu	Galion, OH	419-468-4321
Terex	Tulsa, OK	918-446-5581
VME Americas Inc.	Cleveland, OH	216-383-3000

SECTION G202 – BACKHOES

G202.01 General. The backhoe is a piece of equipment that specializes in excavation. The backhoe consists of a boom, dipper stick, and bucket mounted on a tractor. Backhoes are typically used in trenching because they can excavate to a considerable depth below their base. This characteristic also makes them useful for work such as channel excavation, because the excavation can be done while the tractor remains on dry land. The primary disadvantage of using a backhoe in trenching work is that it can not dig as clean a trench bottom as dedicated trenching equipment. Therefore, a skilled operator along with additional manual labor will be needed to shape the trench bottom after the backhoe finishes the excavation.

Like bulldozers, backhoes are typically categorized by their mountings. Backhoes are mounted on either rubber tires or crawler tracks. There are advantages to each type of mounting. Rubber-tired backhoes (also called backhoe/loaders) are more maneuverable, and can travel more quickly from one place to another. In addition, most rubber-tired backhoes have a loader bucket attached to the front of the tractor, allowing it to be used for work other than excavation. Crawler-track backhoes can be larger than rubber-tired backhoes, and they are better able to work on soft soils because of the larger surface area of the tracks.

The boom on a rubber-tired backhoe is mounted at the rear of the tractor. The boom swings horizontally at its base, and can cover an arc of approximately 180°. Some rubber-tired backhoes have offset booms to allow them to work along guardrails or walls. When the backhoe is working, the weight of the machine plus the soil in the bucket can make it unstable, especially as the boom swings to the side. To stabilize the backhoe, it is equipped with outrigger, stabilizing feet. These feet are located at the rear of the backhoe to carry the weight of the working end. When extended, the feet span an area wider than the tractor itself, and they rest at right angles to the trench. This stabilizes the backhoe, ensuring that it will not tip over during operation. The stabilizing feet should always be extended before beginning excavation. Figure G-5 and G-6 show a typical backhoe.

Figure G-5: Front View of a Rubber-tired Backhoe

Figure G-6: Rear View of Rubber-tired Backhoe

The boom on a crawler-track backhoe is typically mounted on the front of the tractor. The entire tractor assembly, including the boom, engine, and operator's cab, is located on a base that contains the crawler tracks. The entire tractor rotates on a turntable that separates the tractor from the base. This allows the boom to swing horizontally for a full 360°. In addition, because of the size of the base, stabilizing feet are rarely included on a crawler-track backhoe. Figure G-7 shows a crawler-track backhoe.

Figure G-7: Typical Crawler-track Backhoe

G202.02 Backhoe Manufacturers. The following is a partial list of companies in the United States that manufacture backhoes. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	Location	Phone Number
Case	Racine, WI	800-835-2273
Caterpillar	Peoria, IL	309-675-1000
John Deere	Moline, IL	309-675-4381
Dig-It	Springfield, OH	513-323-4981

SECTION G203 – SCRAPERS

G203.01 General. Scrapers, also known as pans, are machines designed to load, haul, and dump loose material. Scrapers can handle a variety of material, from fine-grained soils to rock left from blasting work. Scrapers are used in excavation and embankment work and in base course construction. Figure G-8 shows a typical scraper.

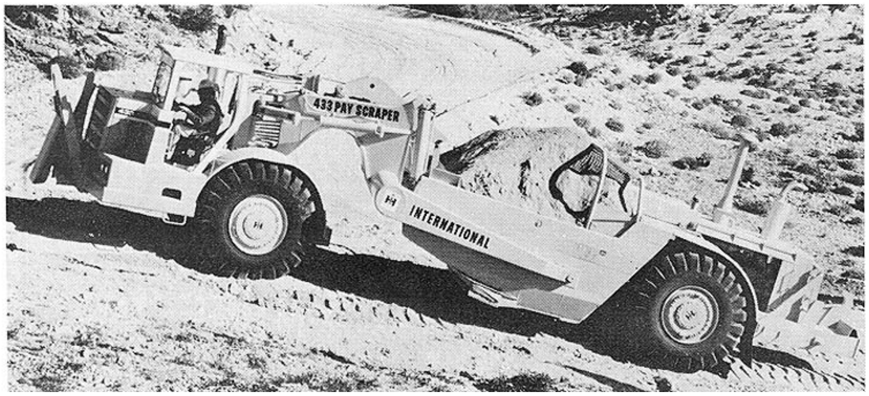

Figure G-8: Typical Scraper

Scrapers consist of two components: the tractor, or prime mover, and the bowl. A typical tractor has two axles, with the bowl suspended from the frame between the front and rear axles. The tractor also holds the engine and the operator's cab.

The bowl of a scraper is essentially a large bucket with an opening on its front side. The current largest bowl size for a scraper is 44 yd^3 (34 m^3), which is roughly the same volume as 160 55-gallon drums. The bowl has three moving parts that are used to control how it functions. These parts are the blade, the apron, and the ejector. The blade is on the front edge of the bowl. It can be lowered into the ground to excavate material or raised while the scraper is hauling material. The apron serves as a gate on the front of the bowl that controls how large the bowl's opening is. It is raised during loading to allow material to enter, and lowered during hauling to hold material in the bowl. The ejector is a curved plate located at the back of the bucket. The ejector can be moved forwards to push material out of the bowl. Figure G-9 highlights the blade, apron, and ejector on a typical scraper bowl.

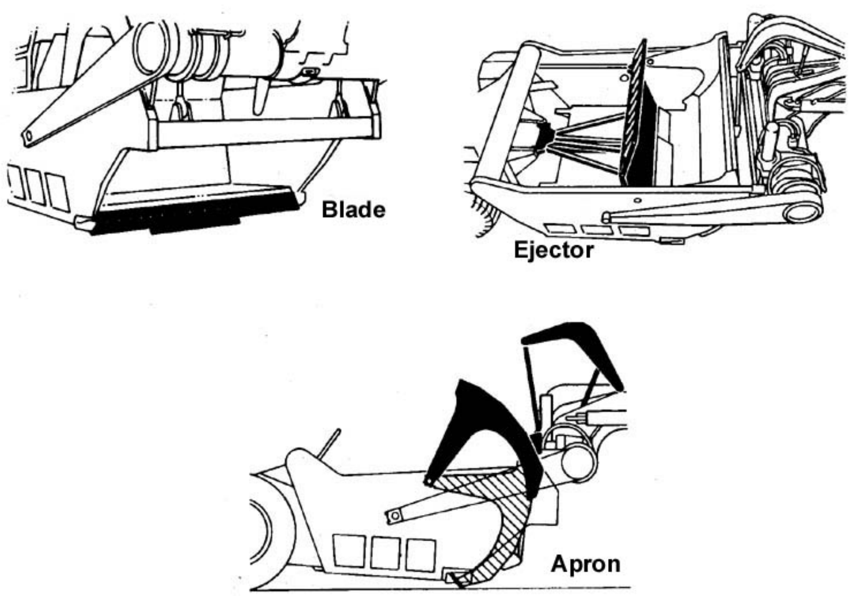

Figure G-9: Parts of a Scraper Bowl

All scraper tractors are mounted on rubber-tires. This gives them better versatility than they would have if they were mounted on crawler tracks. Most scrapers can achieve speeds of 28 mph (45 km/h) while carrying a full load. This makes them economical, because they can move a large volume of soil over a considerable distance at a relatively high speed.

The disadvantage to equipping scrapers with rubber tires is that they can not generate the traction necessary to work on soft soils or to load themselves to capacity. Therefore, all scrapers are designed to have some type of assistance in loading. Scrapers are classified by their method of loading. Scrapers are either push-loaded, push-pull, or elevating.

Push-loaded scrapers are pushed by a bulldozer as they are loading. The combined force of the bulldozer and the scraper ensure that the bowl will be loaded to capacity. Figure G-10 shows a large scraper being push-loaded by multiple bulldozers.

Figure G-10: Push-loading of a Large Scraper

Push-pull scrapers have a push block and bail mounted on the front of the scraper and a push block and hook on the rear of the scraper. Two scrapers are attached by the hook and bail. The rear scraper will push the front scraper as the front scraper loads. Then, the front scraper will pull the rear scraper as the rear scraper loads. Figure G-11 shows a typical push-pull scraper combination.

Figure G-11: Push-Pull Scrapers

Elevating scrapers have a chain elevator that serves as the loading mechanism. As the scraper moves forward, the elevator moves material into the bowl. The advantage of this type of scraper is that it does not require a bulldozer or other scraper to push it. The disadvantages are that the elevator can not handle rock and that the elevator is an additional weight that slows the scraper during hauling. Figure G-12 shows a typical elevating scraper.

Figure G-12: Elevating Scraper

G203.02 Scraping Operations. To excavate soil, the apron on the bowl is raised and the blade is lowered into the ground. As the scraper drives forward, the ground material is forced up and into the bowl. To achieve the maximum capacity of the scraper, the material in the bowl must consolidate itself. This is primarily achieved through the natural action of the material in the bowl, which resembles a pot of boiling water. Material entering the bowl forces material already in the bowl to move upward. As the material falls back down it consolidates the material underneath it.

To aid in the consolidation process, the ejector is used. As scraping begins, the ejector is extended to the front of the bowl. The ejector serves as a deflector that redirects the soil towards the front of the bowl. This helps the material boil up in the bowl and forces the material back on itself, which ensures consolidation.

When the bowl is full, the blade is raised and the apron is lowered. The scraper can then haul the material to another area on the Project or to a designated dumping site off the Project right-of-way. The scraper can complete this hauling quickly and return to the Project to make another pass over the area being excavated.

G203.03 Spreading Operations. A loaded scraper can be used to spread material at a desired thickness. This makes the scraper useful for the construction of embankments and base courses. To spread material, the blade is lowered to the desired height above the fill. The apron is then raised to give the desired lift thickness. As the scraper drives over the area, the ejector moves forward, pushing the material out of the bowl. The length of the lift placed by a scraper will depend on the thickness of the lift and volume of the bowl. Refer to Subsections E202.11 and E301.04 for more information on the use of scrapers in material placement work.

G203.04 Scraper Manufacturers. The following is a partial list of companies in the United States that manufacture scrapers. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	Location	Phone Number
Caterpillar	Peoria, IL	309-675-1000
Terex	Tulsa, OK	918-446-5581

DIVISION G300 – BASES

SECTION G301 – MOTOR GRADERS

G301.01 General. The motor grader is a versatile piece of construction equipment. It is used in the construction of base courses, grading, and other activities that require fine control over the placement of soil. The versatility of some construction equipment, such as bulldozers, comes from the power the equipment can exert on earth materials. The versatility of the motor grader, on the other hand, comes not from its power but from its maneuverability.

The motor grader consists of a tractor, or prime mover, and blade mounted on a frame with a long wheelbase. The wheels on a motor grader are rubber-tired. The blade is located directly behind the front wheels, and hangs below the frame. The cab, engine, and rear wheels are located behind the blade. There are several advantages to this design. Because the blade is connected to the frame at the blade's center and there is nothing above the blade, it can be put in a number of different positions. The blade can be positioned vertically at either side of the frame, or anywhere in between. It can also rotate to either side, allowing it to cast material to the side as it advances. Most new graders have a high lift capability that allows the blade to reach high to the side of the machine. New graders may also have automatic grade control devices attached to the blades that allow for better control of the grading operation.

The maneuverability of the blade requires that the wheels of the grader be flexible in their movements, too. This is necessary to keep the grader stable and to ensure that sufficient force is exerted through the blade to the soil. This flexibility of movement is achieved in several ways. First, the front wheels can be tilted to lean to either side. Second, the rear wheels are full floating, which ensures contact with the ground will be maintained. Finally, there may be a hinged connection between the front and rear portions of the frame. Motor graders with hinged frames are called articulated-frame graders. Motor graders without this hinge are called rigid-framed graders. The advantage of the articulated frame is that it allows for horizontal rotation of the front of the grader, making this type of grader useful for working on side slopes and ditches. Figure G-13 shows a typical motor grader.

Figure G-13: Motor Grader

G301.02 Motor Grader Manufacturers. The following is a partial list of companies in the United States that manufacture motor graders. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	Location	Phone Number
Caterpillar	Peoria, IL	309-675-1000
Champion	Goderich, OH	519-524-2601
John Deere	Moline, IL	309-675-4381
Komatsu	Galion, OH	419-468-4321

SECTION G302 – COMPACTION EQUIPMENT

G302.01 General. Compaction equipment is used to increase the density of subbase, base, and pavement materials. By applying weight to a material, the size of the spaces between individual particles will be decreased. This will result in a higher density for the material, which will make it more stable under a load.

There is a variety of compaction equipment available. The type of equipment that the Contractor uses will depend on the material being compacted. The Specifications require that the Contractor obtain approval of the equipment prior to beginning compaction.

G302.02 Steel-wheel Rollers. These rollers are also referred to as smooth-wheel rollers. They are used for the compaction of sand, gravel, and mixtures of sand and gravel. The material being compacted will determine the kind of steel-wheel roller to be used.

Steel-wheel rollers can be broken down into one of two types: static or vibratory. Static rollers consist of smooth drums that can be filled with water or sand to increase the weight of the roller, and thus the force of compaction. Vibratory rollers have motors attached to the compactive wheel that vibrate the wheel as it is rolling. The frequency of vibrations can be set by the Contractor, and typically varies from 1,000 to 5,000 vibrations per minute.

Steel-wheel rollers come in several different wheel configurations. The self-propelled roller has one steel wheel and two rubber tires, and is usually vibratory. The tandem roller has two steel wheels in a row. One of the wheels is the drive wheel, and the other wheel may or may not be vibratory. Tandem rollers are commonly used to compact asphalt pavement, but may be used to compact soil and aggregate as well. Three-wheel tandem rollers are a variation on the tandem roller, with three wheels in a line instead of two. There are also towed steel-wheel rollers that can be attached to tractors. These are commonly used on smaller areas.

During compaction, material can accumulate on the surface of the steel wheel, possibly resulting in uneven compaction. To prevent this, rollers are equipped with scraper bars and sprinkler devices. It is important to verify that this equipment is in working order to prevent irregularities in the subbase and base course.

Fgures G-14 and G-15 show typical self-propelled and tandem steel-wheel rollers.

Figure G-14: Single Wheel Steel-wheel roller

Figure G15-: Tandem Steel-wheel Roller

G302.03 Sheepsfoot Rollers. These rollers are also called padfoot rollers. They are used to compact fine-grained soils such as clays and silts, as well as mixtures of sand and fine-grained soils.

The sheepsfoot roller is a steel wheel that has a number of steel projections, or feet, welded to it. The roller compacts the soil by kneading it. The feet on the roller can sink through loose soil to a depth of approximately 10" (250 mm). These rollers work best, therefore, when the lift thickness is between 6" and 10" (150 and 250 mm). Lifts of this thickness allow the feet to sink through the loose material and knead it into the lift below, while the smooth surface of the wheel compacts the soil on the surface of the lift. As the lower portion of the lift becomes compacted, the feet ride up into the upper portions of the lift and compact it. Because of the manner of compaction, it is best not to compact a lift all the way to the top surface. By leaving the surface material loose, a better bond will be achieved between that lift and the next lift that is placed.

Like steel-wheel rollers, sheepsfoot rollers can be static or vibratory, and come in several different models. The most common models are self-propelled, tandem, four wheel, and towed. In addition, some sheepsfoot rollers come with small bulldozer-type blades, which allows the roller to perform rough grading or backfilling as it compacts the soil. Figures G-16 through G-19 show examples of some typical sheepsfoot rollers.

Figure G-16: Self-propelled Sheepsfoot Roller

Figure G-17: Self-propelled Sheepsfoot Roller with Blade

Figure G-18: Four Wheeled Sheepsfoot Roller with Blade

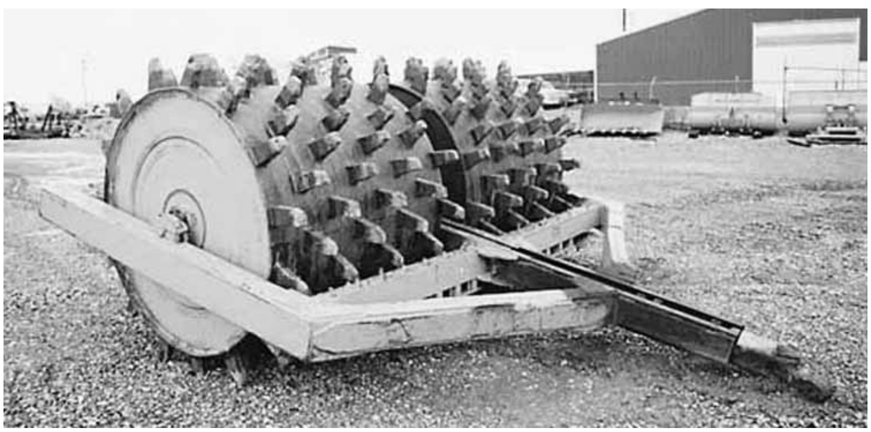

Figure G-19: Towed Sheepsfoot Roller

G302.04 Pneumatic-tire Rollers. Pneumatic-tire, or rubber-tire, rollers can be used to compact almost any kind of soil. These rollers are also used to compact bituminous pavement. However, pneumatic-tire rollers are not useful for compacting aggregate

Pneumatic-tire rollers have a number of tires arranged in two rows. The tires can be small or large, although a roller will have only one size of tire. There are an odd number of tires, and the back row is offset from the front row so that the combined effort of the two rows will compact the soil for the entire width of the roller.

Pneumatic-tire rollers are static only. They work by a combination of kneading and static pressure. Because of the number of tires on a pneumatic-tire roller, a large amount of additional weight can be added to the equipment. This increases the total static compactive force. However, too much weight can break down the soil particles into sizes smaller than the Specifications require. Therefore, the weight of the pneumatic-tire rollers should be monitored to ensure that the resultant base course is in conformance with the Specifications.

Pneumatic-tire rollers are useful because the air pressure in the tires can be adjusted. On many machines, the pressure can be adjusted individually for each tire while the roller is moving. This allows the Contractor to vary the compactive effort. A lower tire pressure results in a smaller compactive force, but allows more of the tire to be in contact with the ground. A higher tire pressure will exert a higher force on the ground over a smaller area. Therefore, it is common for the first passes of the roller to be made with a low tire pressure, ensuring that the entire lift is compacted. Then, a high tire pressure can be used for the final passes to achieve the required density. Because of this variability in compactive effort, the required compaction can usually be achieved in fewer passes than with a different type of roller.

Figure G-20 shows a typical pneumatic-tire roller.

Figure G-20: Pneumatic-tire Roller

G302.05 Manually Operated Compactors. Manually operated compactors have a number of different applications. They are used in areas where it is not possible to use a full size compactor. This includes such applications as compacting the fill over a trench, compacting soil around a footing, or working in areas where large equipment might cause damage to adjacent structures or property.

Manually operated compactors come in a number of different styles depending on the application. There are small steel-wheel rollers, vibratory plate compactors, and rammers. While these smaller compactors allow the Contractor to work in small areas, they require more time and effort to compact the material to the required density. The use of full-size equipment is generally preferred where possible. Figure G-21 shows several manually operated compactors used in road and bridge construction.

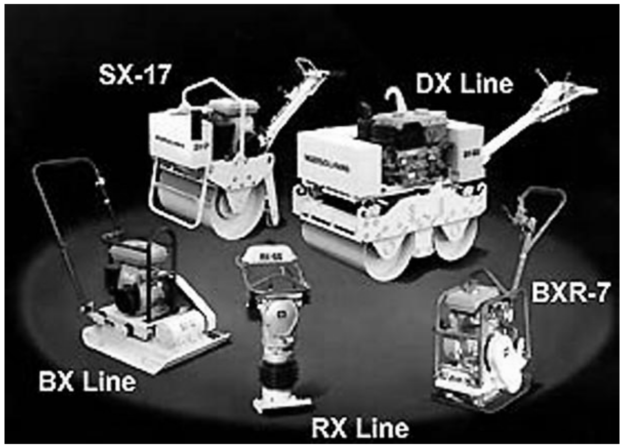

Figure G-21: Manually Operated Compactors

G302.06 Equipment Selection. The choice of compaction equipment is left to the Contractor unless the Specifications require a specific type of compactor. The following table is provided to summarize the applications of the types of compaction equipment discussed above, and to allow the Inspector to evaluate the effectiveness of the Contractor's equipment choice.

Table G-1: Applications of Compaction Equipment

Type of Compactor	Soil Best Suited For	Maximum Effect in Loose Lift in (mm)	Density Gained in Lift
Steel tandem two-axle	sandy silts, most granular materials with some clay binder	4" to 8" (100 to 200 mm)	average[1]
Steel tandem three-axle	same as above	4" to 8" (100 to 200 mm)	average[1]
Steel three-wheel	granular or granular-plastic material	4" to 8" (100 to 200 mm)	average[1] to uniform
Sheepsfoot	clay, silty clay, gravel with clay binder	7" - 12" (175 to 300 mm)	nearly uniform
Pneumatic, small-tire	sandy silts, sandy clays, gravelly sand and clays with few fines	4" to 8" (100 to 200 mm)	average[1] to uniform
Pneumatic, large-tire	All types	up to 24" (600 mm)	uniform
Vibratory	Sand, silty sands, silty gravels	3" to 6" (75 to 150 mm)	uniform
Combinations	All	3" to 6" (75 to 150 mm)	uniform

Notes: 1. The density may increase with depth.
Source: Peurifoy, Robert L., William B. Ledbetter, and Clifford J. Schnexnayder. *Construction Planning, Equipment, and Methods*, fifth edition. McGraw-Hill, NYC, 1996.

G302.07 Compaction Equipment Manufacturers. The following is a partial list of companies in the United States that manufacture compaction equipment. This list is for reference only.

Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	**Location**	**Phone Number**
Case	Racine, WI	800-835-2273
Caterpillar	Peoria, IL	309-675-1000
Dynapac Light Equipment	Carthage, TX	903-766-2318
Ingersoll-Rand	Shippensburg, PA	717-532-9181
Rosco Mfg.	Madison, SD	605-256-6942

DIVISION G400 – BITUMINOUS PAVING EQUIPMENT

SECTION G401 – HOT-MIX ASPHALT PAVERS

G401.01 General. Asphalt pavers are used to place hot-mix bituminous material on a constructed base to the design width and depth for the Project. The Contractor can choose the kind of paver to use on the Project, as long as it meets the requirements of the Specifications. There are many companies in the United States that make asphalt paving equipment. The three largest manufacturers are Barber-Greene, Blaw-Knox, and Cedarapids. While the information and diagrams provided in this Section are based on the equipment manufactured by these three companies, the principles described here are applicable to all asphalt pavers.

Asphalt pavers can be broken down into two basic units: the tractor and the screed. The tractor unit provides the power for the paver. This includes both the power to move the paver along the roadway, and the power to move the bituminous material from the receiving hopper at the front of the paver to the spreading screws at the back of the paver. The screed unit does the work of distributing the bituminous material and leveling it. The screed is adjustable, allowing it to be set for the desired pavement thickness, and allowing it to compensate for variations in the base course. The screed also vibrates, which provides initial compaction to the bituminous material.

Asphalt pavers can be categorized by the kind of propulsion system they use. The pavers fall into one of two categories: rubber-tired or crawler-track. Figures G-22 through G-25 show examples of these two types of pavers.

Figure G-22: Rubber-tired Asphalt Paver

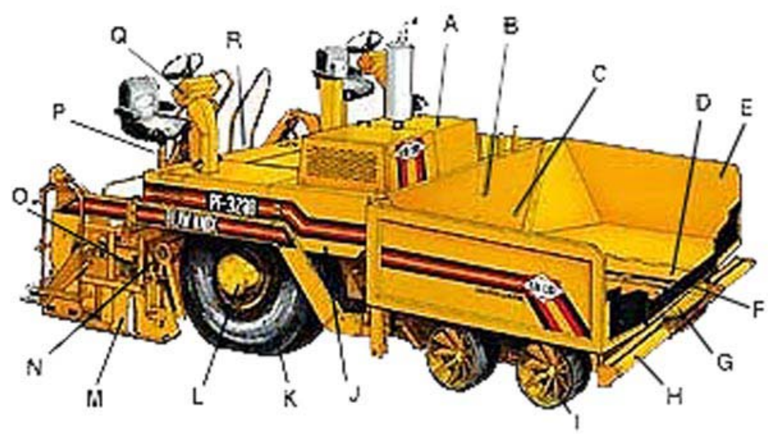

Figure G-23: Typical Parts of a Rubber-tired Asphalt Paver

A. Diesel engine
B. Power flow gates
C. Conveyor tunnel width
D. Auger/conveyor bearings
E. Hopper
F. Conveyor roller chain
G. Conveyor floor plates
H. Choice of oscillating push rollers or truck hitch
I. Offset tandem front bogie with 4 rubber tired wheels
J. Hydraulic oil filtration
K. Drive tire
L. Hydrostatic direct traction drive
M. Maximum paving width 8.23m
N. Auger tunnels
O. Augers
P. Foot-actuated pivot steering
Q. Tilting consoles with gauges and digital ground speed readout
R. Unitized rear feed section

FigureG-24: Crawler-track Asphalt Paver

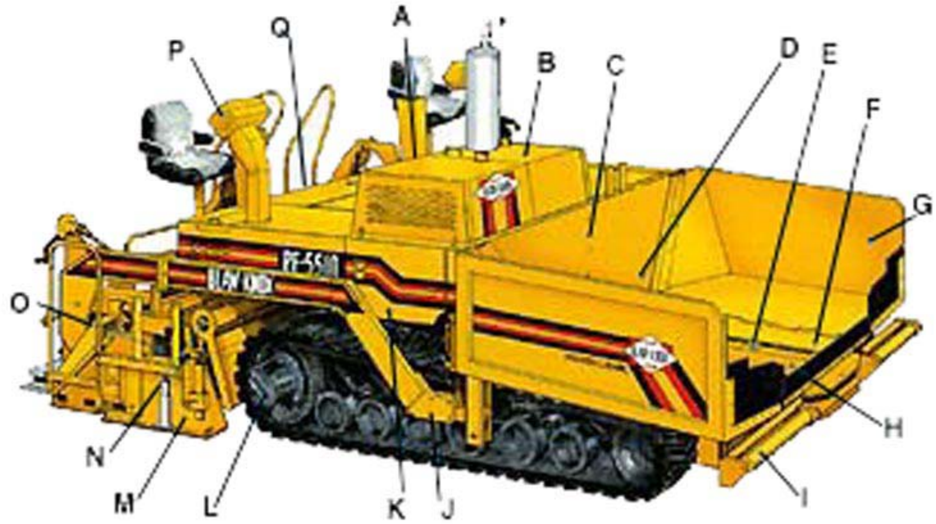

Figure G-25: Typical Parts of a Crawler-track Asphalt Paver

A. Counter-rotating track controls
B. Diesel engine
C. Power flow gates
D. Conveyor tunnel
E. Conveyor roller chain
F. Auger/conveyor bearings
G. Hopper
H. Conveyor floor plates
I. Choice of oscillating push rollers or truck hitch
J. Continuous, flexible, hi-speed rubber track
K. Hydraulic oil filtration
L. Hydrostatic direct traction drive
M. Maximum paving width 27' (8.23 m)
N. Auger tunnels
O. Augers
P. Tilting consoles with gauges and digital ground speed readout
Q. Unitized rear feed section

G401.02 Screed Control. The elevation of the screed, which determines the thickness of the pavement, can be determined in one of two ways: manual or automatic control. The Specifications require that automatic control be used at all times. The only exception to this requirement is that if the automatic control fails or malfunctions, manual control may be used for the remainder of the day. See Subsection 401.05 of the Specifications for more information.

Automatic screed control may be accomplished in one of several ways. The Specifications require that a traveling reference plane be used, and that the Engineer may require the use of a joint matching shoe. Different manufacturers make different kinds of traveling reference planes, but the principle behind this technique is the same. The reference plane is typically a small pipe or beam. The reference plane rests either directly on the pavement or on shoes that hold it above the pavement. A sensor attached to the screed rides on the reference plane. This sensor adjusts the height of the screed in response to changes in the elevation of the reference plane. This system allows the screed to adjust to changes in the grade of the roadway without responding to minor deviations in the surface. The result is a smooth riding surface that does not reflect variations in the underlying base. Figures G-26 and G-27 show how the traveling reference plane works.

Figure G-26: Asphalt Paver Using a Traveling Reference Plane

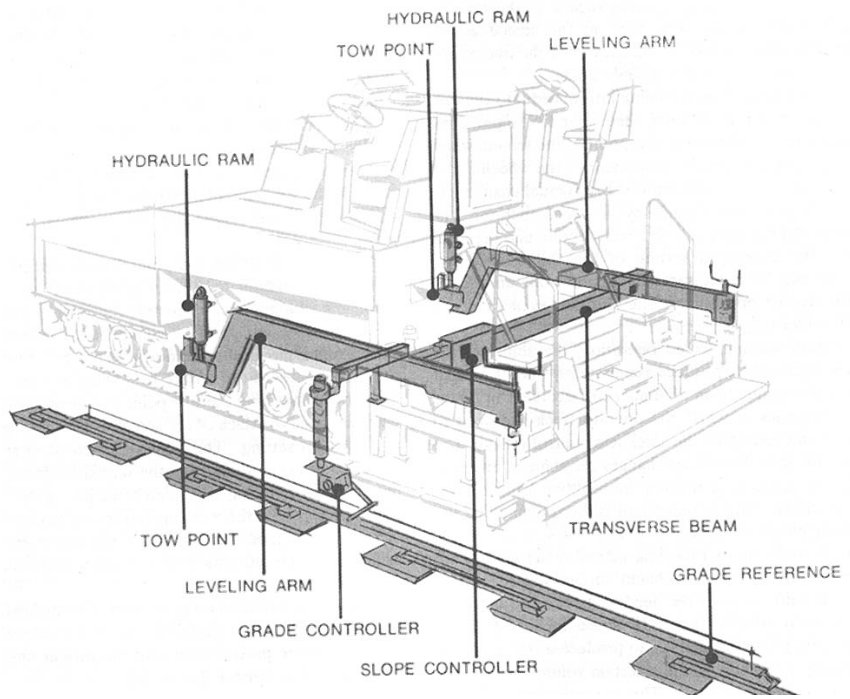

Figure G-27: Automatic Screed Control Using a Traveling Reference Plane

The joint matching shoe is also a grade sensor attached to the screed of an asphalt paver. This device, however, is typically a short shoe or ski approximately 1' (300 mm) long that rides directly on the adjacent grade. It is used when the adjacent grade is to be matched exactly. The joint matching shoe is responsive to minor variations in the adjacent grade. It will change the screed height in response to pebbles or other obstructions on the grade. Therefore, it is most often used when placing a surface course to ensure that the pavement on both sides of the longitudinal joint is of the same grade. Figure G-28 shows a joint matching shoe.

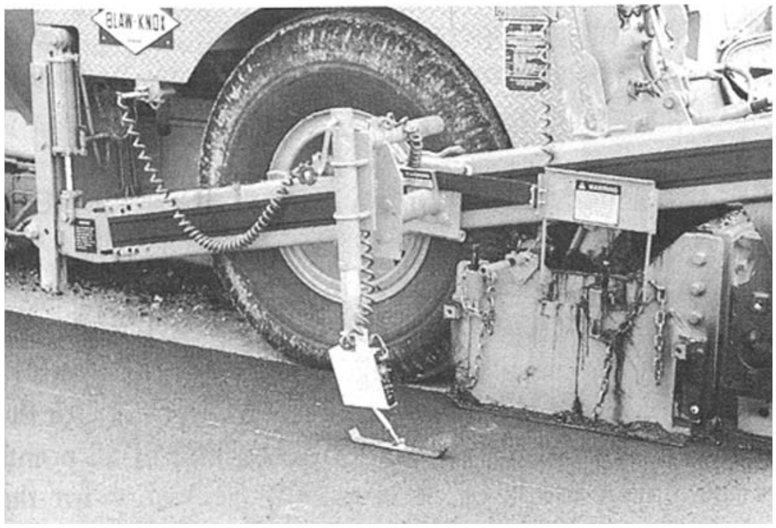

Figure G-28: Joint Matching Shoe Grade Reference

G401.03 Asphalt Paver Manufacturers. The following is a partial list of companies in the United States that manufacture asphalt pavers. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	Location	Phone Number
Barber-Greene	De Kalb, IL	815-756-5600
Blaw-Knox	Buffalo, NY	716-895-2100
Case	Racine, WI	800-835-2273
Caterpillar	Peoria, IL	309-675-1000
Cedarapids	Cedar Rapids, IA	319-363-3511
John Deere	Moline, IL	309-675-4381

SECTION G402 – COMPACTION EQUIPMENT

G402.01 General. Compaction of bituminous pavement serves the same purpose as compaction of a soil or aggregate base course. Compaction forces the particles of material closer together, increasing the strength of the pavement.

Compaction of bituminous pavement is performed with a tandem or three-wheel tandem steel-wheel roller, or a pneumatic-tire roller. All rollers should have scrapers for the wheels, as well as devices that apply water to each wheel during compaction. This equipment is necessary to ensure that the pavement surface is uniform and that no material adheres to the rollers.

Section 401 of the Specifications describes the requirements for rollers used in the compaction of bituminous pavements. Section E401 of this Manual describes the bituminous paving process in more detail, including the compaction operations. Section G302 of this Manual describes the various types of compaction equipment in more detail.

G402.02 Compaction Equipment Manufacturers. For information on compaction equipment manufacturers, refer to Subsection G302.07 of this Manual.

SECTION G403 – MILLING MACHINES

G403.01 General. The terms cold planing, grinding, profiling, and milling refer to the process of removing part or all of a distressed asphalt or portland cement concrete pavement as a first step in the rehabilitation process. Fostered by the energy crisis and the accompanying dramatic increases in the cost of liquid asphalt that occurred during the 1970s, cold planing has gained widespread acceptance and is now in general use throughout the world, especially in developed nations where aging pavement structures require major reconstruction to handle increasing traffic and axle loadings.

Historically, highway agencies around the world have maintained their roadway networks by adding layers of asphalt concrete to existing pavement structures to restore riding qualities, skid resistance, and structural capacity. Prior to resurfacing, failed areas were cut out and replaced, cracks sealed, and low spots or dips filled by wedge or leveling courses.

Such periodic resurfacing was no problem in rural areas, where new layers were added easily with little regard for geometric considerations such as drainage patterns, overhead clearances, or guardrail heights. Even in urban areas, curb height was great enough to allow several inches of asphalt concrete to be placed without disrupting water flow or covering the curbs.

As additional overlays have been placed, however, the extra thickness has caused major problems in many areas, including the need to increase guardrail and drainage inlet heights, and changes in the elevation and slope of the shoulder, leading to further drainage and safety problems. These problems can be overcome by milling and replacing the old material with new or recycled asphalt concrete mixtures.

G403.02 Applications. Although they were initially looked upon primarily as a tool for recovery of valuable paving materials and eliminating the problem of excessive overlay thickness, milling machines can be used to economic advantage in many other maintenance applications to:

(a) texturize the pavement surface to enhance tack and bond, improve skid resistance, and provide a smoother riding surface.
(b) restore pavement geometry to correct grade and slope deviations and eliminate wheelpath ruts.
(c) remove localized failure areas to permit proper repair and patching where required.
(d) increase curb reveal to restore surface water drainage flow patterns along the curb line.
(e) increase overhead clearances to provide the required distance between the road surface and overhead structures.
(f) decrease dead load to reduce the weight of pavement on bridge decks and other elevated structures.
(g) reduce pavement buildup to eliminate the need to raise guardrails and drainage structure elevations.
(h) reduce new leveling course quantities by removing the high spots instead of filling in the low spots.
(i) extend the life of the overlay by providing a constant surface thickness that allows more uniform compaction density.

(j) excavate the entire pavement structure prior to reconstruction at lower cost, with less traffic interruption, and at the same time producing a more easily handled and recycled material.

G403.03 Machines. Machines for this purpose are adaptations of drums for underground mining operations. They are quite heavy and are equipped with high horsepower engines. They consist of a chassis that provides a stable platform for accurate grade control as well as forward propulsion, and rotating drum fitted with teeth that mill off the old pavement material to a predetermined thickness or grade.

The cutting drum contains a variable number (depending on width) of replaceable, tungsten carbide-tipped cutting tools. These tools, arranged in a helix flight pattern, are mounted directly on the drum shell or on flights that permit replacement of several teeth at a time. Figure G-29 shows a typical cutting drum on a milling machine.

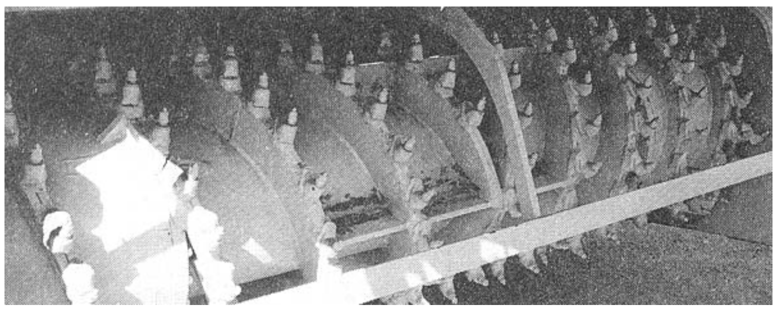

Figure G-29: Cutting Drum on a Milling Machine

The material removed either is left on the pavement for later pickup by loading equipment or is transferred directly into trucks by on-board conveyors. Figures G-30 and G-31 illustrate these two operations.

Figure G-30: Removed Material Discharged on the Pavement

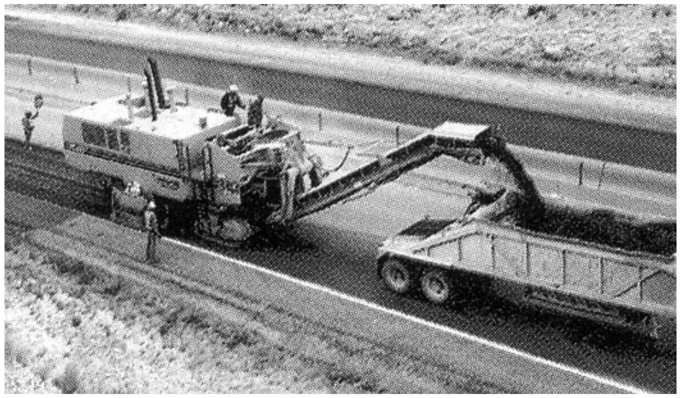

Figure G-31: Removed Material Discharged into a Truck

Milling machines are mounted on either crawlers or pneumatic tires, crawlers generally being preferred for the larger, higher production units and rubber tires for smaller machines where mobility is a major consideration. They operate with the loading conveyor on the front of the machine in the direction of travel (front-loading) or mounted at the rear (rear-loading). Trucks receiving material can work in the same lane as the planer or in an adjacent lane, and the operation can generally be accomplished without closing the roadway to traffic, a major advantage in metropolitan areas. Figures G-32 and G-33 show typical front- and rear-loading milling machines.

Figure G-32: Front-loading Milling Machine

Figure G-33: Rear-loading Milling Machine

The machine can be set to remove a specified thickness of material, thus reproducing any irregularities in the surface over which it is operating, or controlled by some type of automatic control system that allows it to produce a specified grade and slope to improve the geometry and smoothness of the structure.

A variety of machine sizes is available, ranging from those capable of removing a full pavement lane, 12' (4 m) or more wide, in a single pass, to small machines designed primarily for small projects and cleanup work around manhole covers and other obstructions. The most commonly used size is the half lane machine that cuts in the range of 6' (1.8 m) wide and is adaptable to a variety of applications.

Cutter drums generally cut upward into the pavement material from the bottom to top as the machine moves forward. Some machines can also be set up to cut downward into the pavement material from top to bottom. Cutting upward usually produces larger chunk sizes in the reclaimed material and obtains higher capacities, especially when removing the entire pavement structure.

G403.04 Productivity. The productivity of a cold planer is a function of the resistance of the pavement material to the penetration of the cutting tools. Many factors affect this resistance in both asphalt concrete and portland cement concrete materials. Two of the most important are material characteristics and depth of cut.

(a) *Material Characteristics.* The structural integrity of the pavement itself is extremely important. A structurally sound pavement layer will be harder to cut (plane) than a pavement layer that is alligator or fatigue cracked. The hardness or soundness of the aggregate in the mixture, as well as its gradation, will also affect productivity. As the hardness of the aggregate increases and the gradation of the aggregate becomes finer, planing productivity decreases and tool wear increases.

The characteristics of the binder agent used in the mix, either asphalt or portland cement, also have an effect, with the material having the greatest hardness being the most difficult to reclaim by planing. For most asphalt concrete materials, except when the aggregate is of very poor quality, the planer teeth break up the old pavement matrix. The aggregate gradation of the original mix is altered very little, and the reclaimed asphalt concrete chunks are usually asphalt coated.

On portland cement concrete, however, the cutting teeth generally fracture some of the aggregate particles because of the strength of the bond between the cement matrix and the pieces of aggregate. Thus, the productivity of the planing machine, as well as the tooth life, is reduced as the quality of the pavement material being planed increases. Productivity is normally much higher when reclaiming asphalt concrete materials compared to portland cement concrete.

(b) *Depth of Cut.* The depth of cut significantly affects the productivity of this type of reclaiming equipment. As the depth increases, more reclaimed material is produced during one pass of the machine, but forward travel speed of the planer is reduced as the power required for cutting becomes greater. Thus, a tradeoff exists which affects the net productivity of the cold planing machine.

For asphalt concrete materials, the net number of tons of material reclaimed increases as the depth of cut increases, up to some particular thickness (generally in the range of 3" to 4" (75 to 100 mm) depending on the quality of the material). Beyond this thickness, the net productivity decreases because machine forward speed becomes the dominant variable in the productivity tradeoff equation. Thus, the number of tons reclaimed increases as the depth of the cut increases, but decreases after some optimum value.

For portland cement concrete, the depth removed in one pass is normally in the range of ½" to 1½" (15 to 40 mm), depending on the material quality. Because of the difficulty in breaking the bond between the aggregate and the cement binder and because some aggregate particles are fractured in the process, power requirements and tooth wear are greatly increased, making a reduced depth of cut necessary. This results in an increase in the cost of cutting portland cement concrete pavements compared to asphalt concrete materials.

For cuts up to 3" to 4" (75 to 100 mm) in asphalt concrete and ½" to 1 ½" (15 to 40 mm) in portland cement concrete, one planer pass is generally the most efficient removal procedure. For depths exceeding these values, two passes will probably be more efficient.

There can be a wide range of productivity for any given machine. For example, the forward travel speed when cutting can vary from as low as 8' to 10' (2.5 to 3 m) per minute when reclaiming 2" (50 mm) or more of high quality asphalt concrete to as high as 100' to 150' (30 to 45 m) per minute when removing less than 1" (25 mm) of deteriorated asphalt concrete from a roadway surface.

Selection of the proper cutting teeth also affects productivity as well as operating costs, since considerable production time can be lost during tooth replacement. Generally, highest productivity will be achieved if the majority of the teeth used can work during an entire shift without replacement, so that worn teeth can be replaced when the machine would not ordinarily be working.

Selection of the most productive forward speed, number of passes, and cutting tooth can best be done on a trial and error basis on the actual job, and an experienced operator will often make minor adjustments in forward speed to compensate for material variations as the job progresses.

G403.05 Grade and Slope Controls. Most modern milling machines can readily be equipped with automatic grade and slope controls. Both sides of the machine can be regulated, using either dual grade references or a grade control on one side and a slope control on the other side of the machine. The ability to level an existing pavement depends primarily on the type of grade reference specified. If a matching device is used, the machine will duplicate the profile of the surface being matched. If a mobile ski or erected stringline is used, the cold planer will produce a more level surface despite irregularities in the surface being planed.

The specifying agent must determine in advance what end product is required before specifying the controls to be used. A cold planer can be operated using dual grade controls and will then remove a constant depth of material. The machine can also be operated using a combination of grade and slope controls to produce the required cross-section. It is important to note that the planer cannot be used to obtain a constant depth of cut and a constant cross slope at the same time.

G403.06 Machine Selection. It is essential to select the machine that best matches the market in which the Contractor plans to operate. Today, there are two major markets: highway and airport work, and city or urban work. While many milling machines have a high degree of versatility, no one machine can be cost effective for every application. As a hedge against future market changes, the buyer should select the machine that will be most advantageous for the majority of its work and yet be adaptable to other projects if necessary.

For high-volume work, such as on interstate and major secondary highways, the machine must offer the required operating speeds and have the horsepower for deep excavation. Conveyors should have adequate capacity to match machine output.

For urban work, because of congested working conditions and the number of obstacles encountered, a smaller machine that combines high capacity with maneuverability is often the best choice. If many projects include such work as cutting around manhole covers and other obstructions, a smaller utility machine could be a good choice to work with the larger planer. Some larger planers also offer the ability to work right up to obstructions and are therefore a good choice as they eliminate much handwork and use of utility machines.

Generally speaking, rubber-tire mounted machines are more maneuverable and can get around faster on the job, but do not have the sure-footed power offered by crawler machines. Larger, full lane machines have the highest production, but are not as maneuverable as smaller, half lane units. A shorter turning radius is essential for city and urban work, while not so important for highway and airport projects. Three-track crawler machines, which utilize the front track for steering, are generally more maneuverable than four-track or four-wheel machines.

Table G-2 below summarizes the factors affecting machine selection.

Table G-2: Factors Affecting Selection of Milling Machines

Machine Type	Application Requirements													
	Highway work	Airport runways	City streets	Small jobs	Full depth removal	Partial removal only	High productivity	High maneuverability	Short turning radius	Cleanup work	Scattered jobs	Tight quarters	Asphalt	Concrete
Full lane	●	●					●							
Half lane	●	●	●											
Utility				●				●	●	●	●	●		
High operating speeds	●	●					●							
High horsepower	●	●			●		●							●
High conveyor capacity	●	●			●		●						●	
Track mounted	●	●	●		●		●							●
Rubber tires			●	●		●		●	●	●	●	●		
High water storage	●	●					●							●

G403.07 Operating Tips. The various milling machine manufacturers provide detailed information regarding operation and maintenance of their machines, but there are some basic principles that apply to all types of jobs and all machines:

(a) Select the right size and type of milling machine for the job.

(b) Be sure the machine is in good operating condition and that all necessary lubrication and maintenance has been performed. This includes rebuilding and replacing doubtful parts, as downtime on a planing job is very expensive.

(c) Make certain that an adequate supply of cutter teeth and other commonly needed parts are available at or near the job site.

(d) Work out traffic control and truck handling procedures carefully well in advance of job startup.

(e) Plan to have an adequate supply of trucks available for continuous milling operation. Time lost waiting for trucks is a major expense that can often be avoided.

(f) Consider the possibility of working at night – or milling during the day and loading out material at night – especially in urban areas, to avoid problems with traffic and truck access and travel to the dump site.

(g) Carefully plan job procedures for most efficient use of the milling machine and easiest truck access.

(h) Be sure an adequate supply of water will be available, if required.

(i) Allow adequate time for tooth replacement and machine maintenance, preferably during non-working hours, to avoid costly downtime.

(j) Operate the milling machine at the fastest speed consistent with maximum productivity and other requirements such as maximum allowable chunk size, truck availability, etc.

(k) Consider the possibility of using two milling machines for the job, either a large unit for high production and a smaller one for cleanup, or two larger units. Sometimes peak production can be obtained by operating one machine ahead of the other, with each removing a portion of the total depth.

(l) Inspect cutter teeth on a regular basis, as missing, worn, broken, and misaligned teeth cut production and increase power requirements.

G403.08 Milling Machine Manufactures. The following is a partial list of companies in the United States that manufacture milling machines. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	Location	Phone Number
Barber-Greene	De Kalb, IL	815-756-5600
Cedarapids	Cedar Rapids, IA	319-363-3511
CMI Corp.	Oklahoma City, OK	405-787-6020
Roadtec, Inc.	Chattanooga, TN	423-265-0600
Wirtgen America, Inc.	Nashville, TN	615-391-0600

DIVISION G500 – CONCRETE PAVING EQUIPMENT

SECTION G501 – CONCRETE PAVERS

G501.01 General. Concrete paving is a complicated process that requires a variety of equipment. This equipment has to perform a number of functions, including delivering the concrete to the site, spreading the concrete, placing reinforcing steel in the concrete, and finishing the concrete to the proper height, grade, and crown. Taken together, the equipment used in concrete paving is sometimes referred to as a concrete paving train.

Despite the number of operations to be performed and the complexity of the equipment involved, a high-quality concrete roadway is relatively easy to achieve. This is due in part to technological innovations that have greatly simplified the paving process. The following subsections discuss the major pieces of equipment used in a concrete paving train.

G501.02 Concrete Trucks. Concrete must be delivered to the site and placed on the prepared base to be paved in such a manner that the concrete will not segregate or set prior to finishing. Concrete that begins to set before it is placed, spread, and finished cannot be manipulated to achieve the required pavement thickness and grade. Concrete that segregates will not have the necessary strength to support traffic.

There are transit trucks, agitating trucks, and non-agitating dump trucks to haul the batched concrete materials. The type of truck used depends on the method of mixing the concrete. Dry-batched concrete is hauled by dump trucks to the paving site and discharged into the concrete paver. Plant-mixed concrete is hauled in transit trucks, or other permissible trucks, and may be placed on the subgrade with a chute, pump truck, or other method that is in accordance with the Specifications. Figure G-34 shows a concrete pump truck placing concrete.

Figure G-34: Placing Concrete with a Concrete Pump Truck

G501.03 Pavers. There are two types of concrete pavers: fixed-form and slip-form.

(a) *Fixed-form Pavers.* Fixed-form pavers were the first type of concrete paver developed. These pavers travel on forms that are set on the base course before paving begins. The forms are parallel in the direction of the roadway and establish the width of the lane being paved. Because the concrete paver travels on the forms, the forms also establish the grade and profile of the pavement. If the forms are out of alignment or not firmly set on the subgrade, there will be variations in the pavement surface that the Contractor will have to correct. A fixed-form paver will typically consist of steel wheels to ride on the forms, a power train, spreading and finishing equipment, and two bridges that span the lane being paved. The spreading and finishing equipment will be described below. The bridges allow the Contractor's personnel to observe the entire width of the lane as it is being paved. Figure G-35 shows a typical fixed-form paver as part of a paving train.

Figure G-35: Typical Fixed-form Paving Train

(b) *Slip-form pavers.* Unlike fixed-form pavers, where the forms are set and the concrete paver is placed on the forms, slip-form pavers carry their forms with them. Slip-form pavers travel on crawler tracks that ride on the prepared base. The slip-form paver has forms attached to it that move with the paver. This eliminates the need to set forms before paving begins. Slip-form pavers usually have automatic grade controls that adjust the paver based on changes in the grade over which it is paving. This is accomplished with a sensor moving along a stringline or reference plane, or by direct sensing of the base course. Like the fixed-form paver, slip-form pavers typically include a power train, spreading and finishing equipment, and one or two bridges that span the lane being paved. Figure G-36 shows a slip-form paver.

Figure G-36: Slip-form Paving Train

Because slip-form pavers carry their forms with them, the forms only support placed concrete for a relatively short amount of time. Therefore, the concrete has to be able to support itself before it has fully set. This is accomplished in two ways. First, slip-form pavers have forms attached to them that extend as much as 40' (12 m) beyond the back of the paver. This extension provides support for a longer amount of time to allow the concrete to begin to set. Second, the concrete used with slip-form pavers is usually mixed with less water than concrete used with fixed-form pavers. Concrete with a low water content is referred to as stiff concrete.

Where finishing machines are typically separate from a fixed-form paver, they are a part of a slip-form paver. These machines put an extra load on the slip-form paver. In addition, the stiff concrete used with slip-form pavers exerts a high friction force on the forms of the paver, which is an additional load. Because of the load on a slip-form paver, traction is sometimes a problem for the crawler tracks. If a crawler track slips, it can result in a sudden change in the thickness, grade, or profile of the pavement. To overcome this, many slip-form pavers have separate motors for each crawler track to ensure that the tracks receive sufficient power. However, these motors do not make the slip-form paver error-free. Slip-form paving operations should be carefully observed to ensure that the crawler tracks are not slipping during operations.

Regardless of the type of paver used, all concrete paving trains consist of certain types of equipment necessary to complete the pavement. The types and combinations of equipment in a concrete paving train vary by manufacturer and application. The following equipment descriptions apply to all types of concrete pavers, regardless of the specific type used.

(c) *Spreader.* For acceptable quality of the concrete in a pavement, there must not be segregation of the materials. To compensate for long chuting or other pouring methods that cause some segregation, a mechanical spreader is needed to help place the concrete. The spreading is done by a 1' to 2' (300 to 600 mm) diameter auger on a horizontal axis covering the width of the lane being paved. The spreading auger is at the leading edge of the paver. The spreading action is designed to avoid the segregation of material that might occur if the concrete is moved around on the grade by some hand shoveling or vibrators.

Spreaders are very helpful for pavements where reinforcing bar mats or wire mesh is to be placed at about mid-height of the slab’s thickness. On a first pass over a new stretch of paving, concrete is spread over the bottom half of the pavement. Then the spreader backs up, the reinforcing mat is laid on top of the fresh concrete, and the upper half is poured and spread.

(d) *Vibrators.* Vibrators are used to consolidate the concrete. This can be done with vibrating pans or screeds, or immersion spud or tube vibrators attached to the spreader or finisher or other independent equipment. Vibrating pans or screeds are suitable for paving thicknesses of 8" to 12" (200 to 300 mm). Immersion vibrators are required for greater thicknesses. Concrete must be thoroughly vibrated throughout its full depth with just enough mortar brought to the surface to finish satisfactorily. Excess soupy fines or mortar on the surface indicates overwet concrete, too high a sand content, or overfinishing.

(e) *Transverse Finishing Machine.* Following the spreader in the paving train is a concrete finishing machine. For fixed-form pavers, this piece of equipment also rides on the metal side forms for the slab. For slip-form pavers, the finishing machine is usually a part of the paver. The finishing machine has two bridge members that span the lane being paved, and two or more screeds. These screeds are transverse screeds, perpendicular to the centerline of the roadway, and they oscillate across the pavement surface as the paving train moves forward. The first screed is used as a strike-off screed to slice excess concrete from the top of the slab. The second screed levels and finishes the concrete surface. Some finishing machines have three or four screeds. The second or third screed may have a tamping bar to work the coarse aggregate down below the surface. Most transverse finishing machines have an arrangement in their screeds to put a slight arch or convex curvature on the slab's surface.

(f) *Longitudinal Finishing Machine.* The final piece of equipment used to complete the shaping of a concrete pavement is called a longitudinal finisher, or float. For fixed-form pavers, this piece of equipment also rides on the metal side forms for the slab. For slip-form pavers, the finishing machine may be a part of the paver. The longitudinal finishing machine has two bridge members that span the lane being paved. A strike-off bar spans between the bridge members, parallel to the centerline of the roadway. The strike-off bar operates like a screed, cutting off high spots on the slab. The crown of the pavement is built into the supporting track for the strike-off bar, ensuring that the final pavement surface has the required profile.

(g) *Final Finishing.* Final finishing consists of dragging burlap across the pavement surface. This burlap is usually attached to the paving machine or wrapped around a 6" or 7" (150 or 180 mm) aluminum pipe. Figure G-37shows a burlap drag attached to the finishing machine of a slip-form paving train.

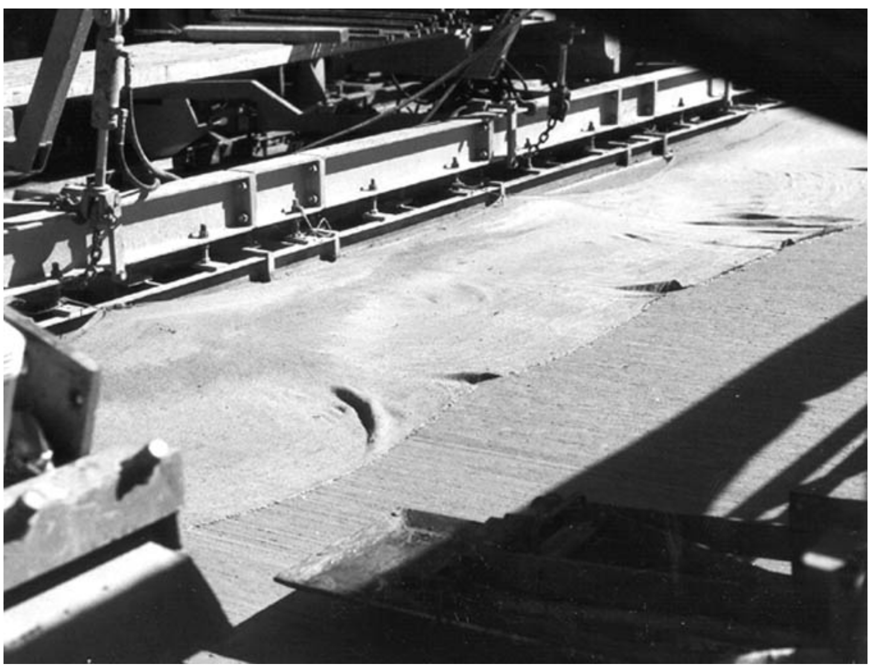

Figure G-37: Burlap Drag Attached to a Finishing Machine

(h) *Dowel Bar Inserters*. Reinforcement is placed in concrete pavements in one of two ways: with a dowel basket or a dowel-bar inserter (DBI). Dowel baskets sit on the pavement subgrade and support the dowels while the concrete is placed over them. DBI's travel with the slip-form paver and automatically insert the reinforcement into the concrete before it is finished. Figure G-38 shows a typical DBI.

Figure G-38: Dowel Bar Inserter on a Slip-form Paver

G501.04 Specialized Paving Equipment. In addition to the standard equipment described above, used to pave concrete roadways, other equipment is available for concrete paving work. This equipment is specialized for paving areas such as bridges, airports, and canals, where standard concrete pavers will not work. Although there are several companies that manufacture this type of equipment, most specialized paving equipment will be referred to as "Bid-Well" equipment. Bid-Well is one of the largest manufacturers of equipment for paving bridges, airports, and canals. Figures G-39 and G-40 show a typical bridge and canal paver, respectively.

Figure G-39: Bridge Paving Equipment

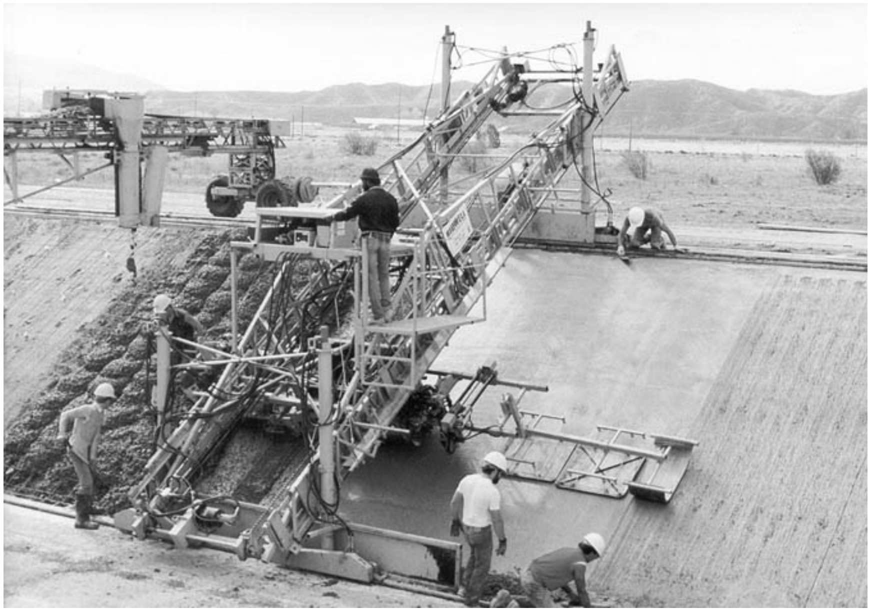

Figure G-40: Canal Paving Equipment

The operation of the various types of specialized equipment is slightly different from the operation of roadway pavers. The equipment has a paving carriage, which typically consists of augers, finishing rollers, and a burlap drag, mounted on a truss that spans the area being paved. The truss travels on fixed rails, sometimes referred to as screed rails, and usually contains a catwalk so workers can observe the paving as it progresses. Figure G-41 shows forms supporting a bridge paver.

Figure G-41-: Forms Supporting a Bridge Paver

When paving with this specialized equipment, the concrete is usually spread as it is placed. The augers on the paving carriage are smaller than the spreaders on roadway pavers, and are used to level the concrete before it is finished. Figure G-42 shows the paving carriage on a typical bridge paver.

Figure G-42: Paving Carriage on a Bridge Paver

The most important thing to check before paving with this type of equipment is that all height adjustments have been made. Because of the versatility of this type of equipment, a number of dimensions have to be adjusted to achieve the correct profile for the finished pavement. These dimensions include:

(a) All four corners of the truss should be the same height from the forms.
(b) The auger and finishing roller should be the correct height above the concrete reinforcement.
(c) The truss should be adjusted to produce the correct crown in the finished pavement.

Once the paving machine has been adjusted, the Contractor will make a dry run before any concrete is placed. This allows the Contractor and the Inspector the opportunity to verify that the paver will operate as required. At this time, bulkheads and end dams can be checked to ensure that the paver will have the correct clearance over these items. Paver manufacturers usually publish detailed instructions for equipment adjustment. This can be a valuable source of information for the Inspector, and information should be requested from the manufacturer if none is available.

G501.05 Paver Manufactures. The following is a partial list of companies in the United States that manufacture concrete pavers. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	Location	Phone Number
Bid-Well	Canton, SD	605-987-2603
CMI Corp.	Oklahoma City, OK	405-787-6020
Gomaco	Ida Grove, IA	712-364-3347
M-B-W	Slinger, WI	800-678-5237

SECTION G502 – PROFILOGRAPHS

G502.01 General. A profilograph is a device that measures the roughness of a pavement surface. The quality of a road is often judged by others in terms of how smooth the road is. A road that has a lot of bumps or irregularities tends to result in an unpleasant ride. The profilograph is used to ensure that the Contractor produced a smooth riding surface.

The Specifications require that a profilograph with non-uniformly spaced wheels, often referred to as a California-type profilograph, be used.

A profilograph is used to record the surface roughness by moving longitudinally over the pavement at less than 3 mph (5 km/hr). The record is analyzed to determine the rate of roughness and to identify bumps that exceed a specified threshold. Figure G-43 shows a typical articulated multi-wheeled profilograph.

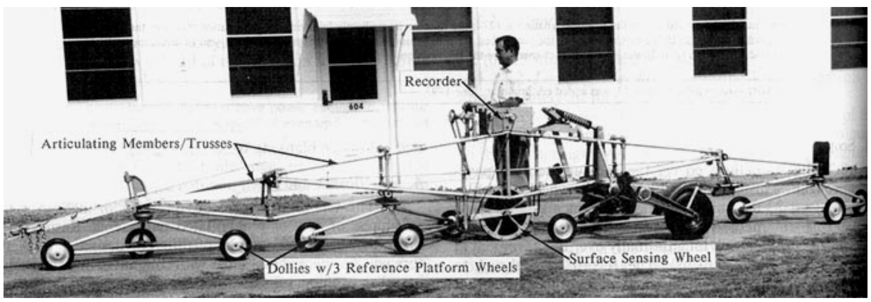

Figure G-43-: Typical Multi-Wheel Profilograph

A typical profilograph is at least 23' (7 m) long. The profilograph consists of a reference platform comprised of dollies articulated by rigid members or trusses so that all the wheels support the profilograph. All profilographs have at least twelve reference-platform wheels.

Electronic surface-sensing equipment and a data recorder are mounted on the profilograph frame. The surface-sensing equipment must be mounted at the center of the profilograph, but the data recorder can be mounted anywhere on the profilograph. Figure G-44 shows the surface-sensing wheel on a typical profilograph.

Figure G-44: Profilograph Surface-sensing Wheel

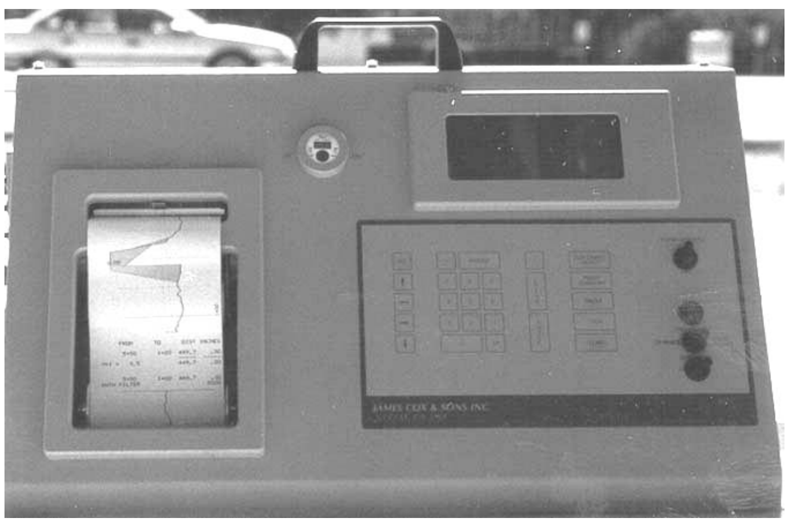

Figure G-45: Graphic Data Recorder on a Profilograph

G502.02 Optional Templates. The profilograph may be equipped with optional templates, if desired. Optional templates consist of the following:

(a) *Blanking Band Template.* The template is a clear plastic strip that is at least 4" (100 mm) long and approximately 2" (50 mm) wide. The center of the template is marked with an opaque strip the width of the stipulated blanking band throughout its length. The width of the blanking band for PCC construction and PCC concrete pavement rehabilitation is 0.2" (5 mm). The width of the blanking for new Hot Mix Asphalt pavement is 0" (0 mm). Lines are marked every 0.1" (2.5 mm) above and below the blanking band.

(b) *Excessive Height Template.* The template is a clear plastic piece marked with four parallel 1"± 0.02" (25.4 ± 0.5 mm) lines spaced at 0.1" (2.5 mm) on center. This template indicates the stipulated cutoff height distance from a straight edge on the template. Two small holes may be drilled to fix the ends of the line. Figure below shows an excessive height template on a profilograph output.

G502.03 Terms. The following are terms commonly used in surface testing with a profilograph.

(a) *Blanking Band.* A band of uniform height with its longitudinal center positioned optimally between the highs and lows of the surface record depicting at least 100' (30 m) of pavement. Figure below shows a typical blanking band.

(b) *Cutoff Height.* A specific distance of a high on the surface record from a chord representing 25' (7.62 m) on the longitudinal scale. The chord may represent less than 25' (7.62 m) if it is from the lows on each side of the high. Figure shows the cutoff height on a profilograph output.

(c) *Rate of Roughness.* Sum of the roughness divided by the longitudinal distance covered by the blanking band.

(d) *Roughness.* Height of each continuous scallop rounded to the nearest 1 mm, except those less than 1/32" (0.8 mm) vertically and 2' (0.6 m) longitudinally.

(e) *Scallops.* Excursions of the surface record above and below the blanking band. Figure G-46 below shows scallops on a profilograph output.

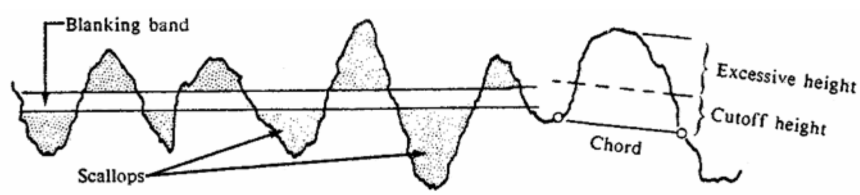

Figure G-46: Sample Graphical Output from a Profilograph

G502.04 Safety Considerations. Since profilographs in the testing mode are moved no faster than 3 mph (5 km/hr), they should not be operated near traffic without proper traffic-control devices and procedures that ensure the safety of testing personnel and the public.

G502.05 Profilograph Manufactures. The following is a partial list of companies in the United States that manufacture profilographs with non-uniformly spaced wheels. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	Location	Phone Number
James Cox & Sons	Colfax, CA	530-346-8322
Paveset America, Inc.	Denver, CO	800-719-PAVE
Surface Systems & Instruments	Sausalito, CA	800-662-5656

SECTION G503 – AUTOGRADER

G503.01 General. An autograder, also known as a trimmer-reclaimer or trimmer-spreader, is a machine used for final preparation of the subgrade, subbase, or base course prior to concrete paving. The first autograder was manufactured by CMI Corp., the same company that makes much of the concrete paving equipment described above. It is from CMI that the autograder originally got its name. The autograding equipment manufactured by CMI is also the most popular and widely used. Therefore, while the equipment discussed here will be referred to as an autograder, the Inspector should keep in mind that the operating principles described apply to most types of trimmer-reclaimers currently available.

In many ways, the autograder is similar to the milling machine described in Section G403. The autograder also has many of the same features as slip-form concrete pavers. In fact, most autograders can be used to trim the pavement subgrade, spread the base course material, trim the base, and then spread the concrete. Figure G-47 shows a typical autograder.

Figure G-47: Typical Autograder

G503.02 Drive System. Autograders are usually mounted on crawler tracks, although they may be mounted on rubber tires. Most autograders have either three or four tracks, depending on their width. Three-track models are used for single lane trimming, and four-track models are used for full-width trimming. Each crawler-track assembly is equipped with its own hydraulic leg so that the elevation of all four corners of the machine can be independently controlled.

G503.03 Trimming System. A typical autograder has two rotating drums that handle the trimming and material handling work. The trimmer head, or cutter, has a set of cutting teeth arranged in a helix flight pattern around the one of the drums. The other rotating drum is an auger. The auger distributes trimmed material to the sides of the autograder or acts as a spreader for base material or concrete.

Autograders are also equipped with moldboards, continuous metal pieces located behind the trimmer that extend across the width of the autograder. The moldboards have grader blades at their bases that perform the same function as the motor grader blade described in Section G301. The front moldboard is located directly behind the trimmer. It carries the trimmed material forward as the autograder advances. This material will fill in low spots in the base course or pass to the sides of the moldboard and out of the lane being trimmed. The rear moldboard is located behind the auger. It can carry trimmed material forward, push the material to the side, or leave the material in a windrow behind the autograder. In addition to controlling the flow of trimmed material, the moldboards can also be used to control the crown in the road.

As an alternative to controlling trimmed material with the moldboards, many autograders can be equipped with a conveyor system. This system is mounted at the rear of the autograder. The rear moldboard is set to guide trimmed material to the conveyor, which then moves the material behind or to the side of the machine, as shown in Figure G-48.

Figure G-48: Autograder Conveyor Attachment

G503.04 Grade Control. The grade to which the autograder trims is usually controlled by one or two stringlines. Automatic sensors ride on the stringlines and translate changes in the grade of the stringline to changes in the height of the trimmer head and moldboards. A typical autograder will have four separate sensors in order to accurately control the elevation of the machine. Figure G-49 shows an autograder following a stringline.

Figure G-49: Autograder Following a Stringline

G503.05 Paver Manufactures. The following is a partial list of companies in the United States that manufacture autograders. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	Location	Phone Number
CMI Corp.	Oklahoma City, OK	405-787-6020
Gomaco	Ida Grove, IA	712-364-3347

Revised: January 2004

DIVISION G600 – STRUCTURES

SECTION G601 – CRANES

G601.01 General. The construction equipment that falls under the term “cranes” represents a broad class of machines. The typical crane is used to lift and place loads. Modifications on the basic crane structure allow it to be used for other activities such as dredging and pile driving. These two activities and the equipment related to their performance are discussed elsewhere in this Manual. The information in this Section relates specifically to cranes that are used to lift, move, and place material for structural work on a Project.

Cranes can be broken down into several major types based on their drive system and type of boom. The cranes that are most likely to be used in highway construction work are crawlers, trucks, and rough-terrain cranes. Each of these cranes is discussed in the following subsections.

G601.02 Crawler Cranes. Crawler cranes are designed to lift and move a heavy load. Cranes of this type consist of a superstructure mounted on a set of crawler tracks. The superstructure rests on a turntable that enables the crane to rotate in a full circle. The boom on the superstructure is a lattice-type boom. The advantage of this type of boom is that it can carry heavier loads than other types of booms. The disadvantage of the lattice boom is that it must be disassembled for transport.

The crawlers on the crane serve three purposes. First, they distribute the weight of the crane over a large area, allowing it to operate on soft soils. Second, they provide better traction for motion over the terrain and on slopes. Third, they provide good stability, allowing the crane to have a higher lifting capacity.

The disadvantages of the crawlers are that this type of crane moves very slowly and can not be driven long distances on paved roads. The transmission on this type of crane has a number of low gears to deliver the power necessary to move over soft soils and on slopes. However, the size and weight of this type of crane limit its travel speed of 0.5 to 1.5 mph (1 to 2.5 km/h). Due to this low speed and the weight of the crane, crawler cranes must be moved to and from the site on a tractor-trailer, “low-boy”, or rail car. Large crawler cranes often have to be taken apart and loaded onto several different cars. Therefore, the size and speed of the crawler crane dictate that it be used in applications where little movement will be required. Figure G-50 shows a typical crawler crane.

Figure G-50: Crawler Crane

G601.03 Truck Cranes. A truck crane consists of a superstructure set on rubber-tire truck chassis. These cranes are designed to have more maneuverability on the Project site and on the road than crawler cranes. This reduces transportation costs and makes truck cranes more desirable than crawler cranes when the equipment is needed for a short amount of time. The trade-off for the greater maneuverability of a truck crane is that it cannot drive on the soft soils that a crawler crane can.

The truck crane's maneuverability comes in part from its transmission. The gears are arranged so that an average crane can reach a road speed of 35 to 50 mph (55 to 80 km/h). There are also a number of creeping gears that allow the crane to move at very slow speeds. The Contractor must exercise caution when using these creeping gears. Some of them provide so much power that using them for anything other than creeping on reasonably good ground will twist the drive shaft off.

Truck cranes have a fully rotating superstructure that holds the boom. Many truck cranes have a single engine that powers both the truck and the boom. These cranes have either one cab for control of both the truck and the boom, or separate cabs for control of each. Larger truck cranes will also have separate power sources for the truck and boom.

Truck cranes can have lattice booms or telescoping booms. For truck cranes that are driven on the road, telescoping booms are preferable. Telescoping booms consist of multiple sections that fit into one another. The booms are hydraulically operated and can be extended or contracted while the boom is loaded. This allows for a greater flexibility of movement than a lattice boom; however, telescoping booms are typically not as strong as lattice booms. Despite the strength limitation, telescoping booms are desirable on truck cranes because they allow for quick set-up and break-down of the cranes on the Project site, and easy transport from Project to Project. Figure G-51 shows a typical truck crane.

Figure G-51: Truck Crane

G601.04 Rough-Terrain Cranes. Like truck cranes, rough-terrain cranes consist of superstructures mounted on rubber-tire truck chassis. However, where truck cranes can have as many as nine axles, rough-terrain cranes always have two axles. Because of their smaller size, these cranes also have lower lifting capacities than truck cranes.

Rough-terrain cranes are intended for work in hard-to-reach areas. They are smaller than truck and crawler cranes to allow greater maneuverability. They are also equipped with oversized rubber tires to allow the cranes to travel over different types of terrain. Despite these characteristics, rough-terrain cranes are not limited to rough-terrain work. These cranes can typically reach a road speed of 30 mph (50 km/h). This road speed, combined with their maneuverability, makes rough-terrain cranes useful to load and unload materials and perform other simple lifting operations. They can also be used for work next to existing roadways, where their smaller size allows them to fit onto a highway shoulder or other narrow area.

The superstructures of rough-terrain cranes are fully rotating, and always support the boom. On some rough-terrain cranes, the cab is also located on the superstructure. On other rough-terrain cranes, the cab is mounted on the truck chassis. In both cases, the drive controls and the boom controls are located in the cab.

Rough-terrain cranes use telescoping booms. These booms are also used on truck cranes, and are described in Subsection G601.03. Telescoping booms on rough-terrain cranes are typically smaller than those on a truck crane, which reflects the smaller overall size of the rough-terrain crane. Figure G-52 shows a typical rough-terrain crane.

Figure G-52: Rough-terrain Crane

G601.05 Safety Considerations. Precautions are taken during the design of a crane to ensure that it will operate safely and effectively. These precautions are only effective if proper safety procedures are followed on the Project. These precautions include observance of the lifting capacity, awareness of the wind, observance of safe hoisting and braking speeds, and observance of proper stabilization procedures.

(a) *Lifting capacity.* Because cranes are used for heavy lifting, they are designed to ensure that they will be safe and stable. This safety of the design is defined in part by the lifting capacity of the crane. The lifting capacity is a percentage of the tipping load for a particular crane. The tipping load is the minimum load that will tip the crane over. Figure G-53 illustrates the standard tipping line locations for a crane. This diagram should only be used as a general guide, because the tipping lines for every crane are different.

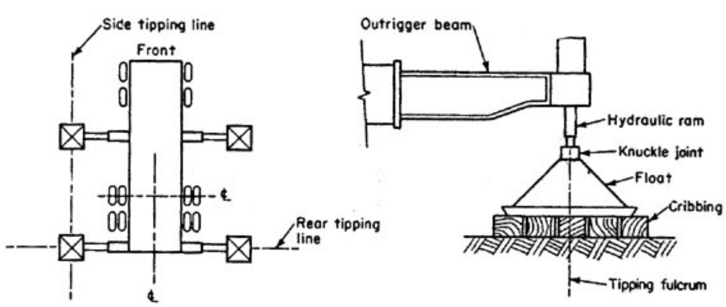

Figure G-53: Tipping Lines for a Crane

The lifting capacity of a crane is a function of the load on the crane and the radius from the crane body to the load. For a given load, the longer the radius, the further the load is from the crane body and the more likely the crane is to tip over. The tipping load, and thus the lifting capacity, is different for different cranes. Each manufacturer will provide information on the lifting capacity for the crane, including a diagram showing the relation between radius and load for the crane. The Contractor must work within the specified limits for the equipment being used. In addition, the Engineer must approve all equipment prior to the Contractor using the equipment. This prior approval allows the Engineer to ensure that the equipment being used is suitable for the work being performed.

(b) *Wind:* The wind will act as an additional load on both the boom and the object being lifted. A strong wind can turn a safe lifting operation into an unsafe one by imposing the additional load. Therefore, the Inspector should always be aware of the wind conditions when a crane is being used on the Project. There are requirements for the wind speed that a loaded boom must be able to withstand. However, these requirements consider the wind force on the boom only, not on the object being lifted. Therefore, the Inspector must consider the object when judging the safety of lifting operations.

Even when a crane is not working, it is susceptible to wind loading. In extremely windy conditions, above roughly 50 mph (80 km/h), booms may be susceptible to tipping from the wind load alone. Under such conditions, the crane should be moved or the boom lowered to minimize the effects of the wind.

(c) *Hoisting and Braking Speed:* The hoisting and braking speed of a crane is determined in part by the weight of the object being lifted and the capacity of the equipment. The heavier an object is, the slower the maximum hoisting speed will be, regardless of the crane being used. Trying to hoist a heavy object at a high speed, or trying to brake a heavy object moving at a high speed, can result in damage to the crane.

Regardless of the limitations of the equipment, rapid acceleration and braking should always be avoided. These sudden accelerations and decelerations exert an additional force on the crane beyond the weight of the object being lifted. This additional, sudden force can damage the boom. In addition, the total force on the crane in this case may exceed the lifting capacity of the crane. Therefore, the Inspector should be aware of the hoisting and braking speeds of cranes used on the Project. The Contractor should be asked to stop unsafe hoisting and braking practices immediately, in accordance with Subsection 105.01 and 108.06 of the Specifications.

(d) *Stabilization Procedures.* All cranes are equipped with a method to stabilize them while working. For crawler cranes, the stability of the crane is achieved by virtue of the crawler base itself. The width and length of the base and the full ground contact between the crawlers and the ground provide a high resisting force to tipping. To increase the stability of crawler cranes, the tracks are extendable on many of the more recent models. This widens the overall base of the crane to increase the stability.

Truck and rough-terrain cranes are equipped with outrigger floats to provide stability. They widen and lengthen the crane's base to provide greater resistance to tipping. The floats generally rest on wood or metal plates to distribute the load across a larger area of the ground surface. When working on paved areas, this technique reduces damage to the pavement that would be caused by the outrigger feet alone.

The Inspector should ensure that a crane's stabilizing system is properly enabled before work begins. This includes ensuring that the crane is on nearly level ground, and that the outrigger floats or crawler tracks are fully extended and locked. For truck or rough-terrain cranes, the outrigger floats should also be resting on relatively stable ground.

G601.06 Crane Manufacturers. The following is a partial list of companies in the United States that manufacture cranes. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	Location	Phone Number
Aurora Crane Co.	Seattle, WA	206-622-9961
Detroit Hoist & Crane	Sterling Heights, MI	800-521-9126
Grove Worldwide	Shady Grove, PA	717-597-6300
National Crane	Waverly, NE	402-786-6300
Terex Cranes	Conway, SC	803-349-6900

G601.07 References. For additional information, see *Cranes & Derricks,* by Howard I. Shapiro, published by the McGraw-Hill Company, ©1980.

SECTION G602 – PILE DRIVING EQUIPMENT

G602.01 General. A pile is a structural member that is driven into the ground to provide support for a structure. Piles are made from timber, concrete, or steel, and come in a variety of shapes and sizes. They can be driven into the ground vertically or at an angle. The material, size, and angle of the piles used on a Project are determined during the design phase. These characteristics will impact the type of pile driving equipment that the Contractor uses.

The ground material the piles are driven into also impacts the choice of pile driving equipment. Piles can be driven through gravel, sand, or fine-grained soils with a range of moisture contents. During driving, friction will build up between the ground material and the pile. The amount of friction expected, as well as the material present, will play a role in determining the best type of pile driving equipment.

Section 618 of the Specifications discusses pile materials. Sections 619, 621, and 622 discuss pile-driving requirements. The Specifications allow two types of pile hammers to be used: pneumatic and diesel. The Specifications also describe the use of other pile driving equipment, such as pile helmets, leads, and water jets. There are limitations on the use of each type of pile driving equipment based on the material of the pile being driven. The Specifications describe these requirements and limitations in detail. These requirements will not be duplicated in this Section. Instead, equipment descriptions and construction procedures will be discussed here. Review of this Section and the pile driving Sections of the Specifications will help prepare the Inspector to oversee pile-driving operations on the Project.

Revised: January 2004

G602.02 Pneumatic Hammers. A pneumatic hammer consists of a stationary cylinder and a freely falling weight called a ram. The hammer is connected to a boiler that provides steam or air at a high pressure. The ram is lifted by applying steam or air pressure to a piston that is attached to the ram. There are three types of pneumatic hammer: single-acting, double-acting, and differential.

(a) *Single-acting hammers.* The single-acting hammer is the simplest pneumatic hammer. Steam or air pressure raises the ram to top of the hammer cylinder. The pressure is then released, and the ram falls and strikes the head of the pile.

The energy of the single-acting hammer comes from dropping a heavy ram at a low velocity. This combination of weight and speed ensures that a large portion of the energy will be transferred to the pile. The low velocity also decreases the possibility of damaging the head of the pile during driving.

The low velocity of the ram is achieved by using a relatively short fall distance. The typical fall distance from the top of the hammer cylinder to the pile head is 3' (1 m), though this height may vary from 1' to 5' (0.3 to 1.5 m). The use of pneumatic pressure combined with the short height of the hammer cylinder allows the average single-acting hammer to strike 40 to 60 blows per minute.

Single-acting hammers are used when heavy piles or piles of low compressive strength are being driven. These hammers are also used when the piles are being driven into stiff clay, gravel, or other dense soils.

(b) *Double-acting hammers.* The double-acting hammer has the same basic components as the single-acting hammer. Steam or air pressure is applied to a piston to elevate the ram to the top of its stroke. Pressure is then applied to the top of the piston to accelerate the ram on its downward stroke. This allows the double-acting hammer to deliver more energy per blow than a single-acting hammer of equal weight, and to do so with a shorter hammer stroke. The disadvantage of the double-acting hammer is that the higher energy hammer is more likely to damage or deform the pile than a single-acting hammer.

The double-acting hammer typically has a blow rate twice as high as a single-acting hammer of equal energy rating. Because of the high energy and high blow rate, double acting hammers are preferred for driving light- or medium-weight piles into soils with normal frictional resistances. The rapid blow count keeps the pile in almost constant motion, preventing the build-up of static friction forces between the pile and the soil. This reduces the time required to drive each pile.

(c) *Differential-acting hammers.* The differential-acting hammer is a modification that combines characteristics of the single- and double-acting hammers. The ram, stroke length, and piston size are comparable to those for a single-acting hammer. However, after the steam or air pressure raises the ram, it is vented over the piston to accelerate the ram on its downward stroke. Thus, the differential-acting hammer behaves like a single-acting hammer with respect to size and a double-acting hammer with respect to blow rate.

The differential-acting hammer is used for the same applications as the single-acting hammer. The differential-acting hammer can drive a pile in roughly half the time it takes a single-acting hammer of the same size. The differential acting hammer also uses approximately twenty-five percent less steam per pile than the single-acting hammer.

Pneumatic hammers come in two styles: open and closed. Open hammers are those that have visible rams. These are useful for monitoring the stroke height of the ram. Closed hammers are those that completely enclose the ram. The advantage of a closed hammers is that it can be used under water.

Figure G-54 shows a photograph and diagram of a typical single-acting hammer.

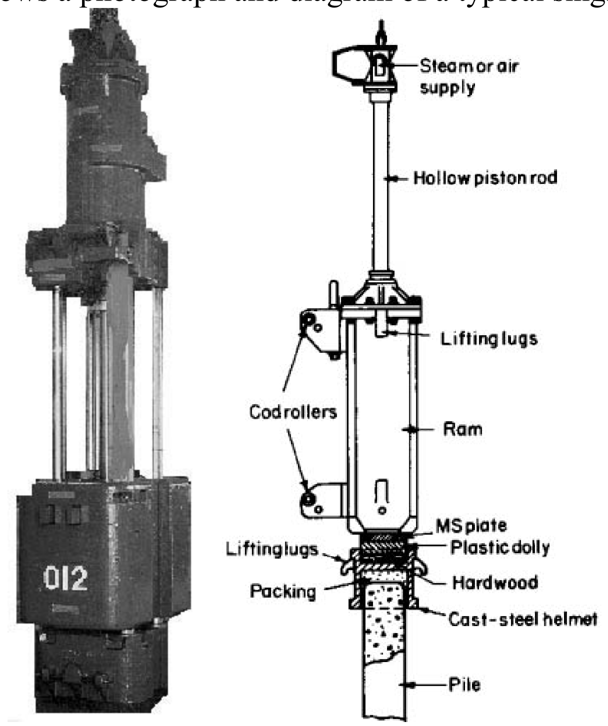

Figure G-54: Pneumatic Single-acting Hammer

G602.03 Diesel Hammers. A diesel hammer is a completely self-contained unit that includes both the hammer and the power source. The diesel hammer is easier to move and set-up than a pneumatic hammer because it does not require a boiler or other external power source. A complete diesel hammer consists of the cylinder, ram, anvil, fuel tank, lubricating-oil tank, fuel pump, injectors, and a mechanical lubricator.

The diesel hammer functions much like a diesel engine in an automobile. The hammer is set in place over the pile, and the anvil is secured to the pile head. The hammer is started by raising the ram to the top of its stroke with the hook on the crane and then letting the ram fall free. As the ram nears the bottom of its stroke, it activates the fuel pump. This injects fuel into a combustion chamber between the ram and the anvil. As the ram continues to fall, it compresses the fuel to its ignition point. The fuel explodes, which drives the pile downwards and the hammer upwards. Once the hammer is started, the pile driving cycle is self-perpetuating.

There are two styles of diesel pile drivers: open-ended and closed-ended. These two styles can also be described as single-acting and double-acting. The open-ended diesel hammer is open at its upper end, so that the ram is not restricted in its rebound. The height of the rebound of the ram is the stroke length for the following blow. As the pile is driven deeper, the resistance to driving will increase. This can be observed as an increase in rebound height. This greater height, in turn, gives a greater stroke length for the following blow. Thus, open-ended diesel hammers will increase the energy per blow as the pile's resistance to driving increases. Open-ended diesel hammers are also called single-acting because there is no added acceleration force during the downward stroke of the ram.

The closed-ended diesel hammer is closed at its upper end. As the ram rises on its upstroke, it compresses air behind it at the upper end of the cylinder. The compressed air exerts an additional accelerating force on the ram on its downward stroke. As the pile is driven deeper, the resistance to driving will increase. This will result in an increased rebound height. This additional height will compress the air in the upper end of the cylinder even more, which will increase the accelerating force during the downward stroke. Thus, closed-ended diesel hammers will increase the energy per blow as the pile's resistance to driving increases. Closed-ended diesel hammers are also called double-acting because there is an added acceleration force during the downward stroke of the ram.

The advantages of diesel hammers are that they are convenient for use in remote areas, they operate well in cold weather, and the energy per blow increases as the resisting force increases. The disadvantages are that energy per blow is difficult to determine, diesel hammers do not operate well when driving piles into soft ground, and the blow rate is less than for a pneumatic hammer.

G602.04 Driving Helmets and Pile Cushions. A driving helmet, also called a driving cap or a driving head, is a piece of accessory equipment that is placed on top of the pile being driven. The driving helmet uniformly distributes the energy from the ram to the pile. The driving helmet also protects the head of the pile from damage due to the repeated impact of the hammer. Driving helmets are made from steel and are shaped to fit the particular pile being driven. However, the driving helmet should not restrict the pile if it tends to rotate during driving.

Pile cushions, also called cushion blocks, are used to soften the blow of the ram to prevent damage to the head of the pile. They are placed between the pile head and the driving helmet. Pile cushions are primarily used with concrete piles. The cushions are made from seasoned wood that is cut to fit inside the driving helmet and is at least 6" (150 mm) thick.

Figure G-55 below shows a driving helmet and pile cushion installed on a pile. Subsection 619.04 of the Specifications states the requirements for driving helmets and pile cushions and should be referred to for additional information.

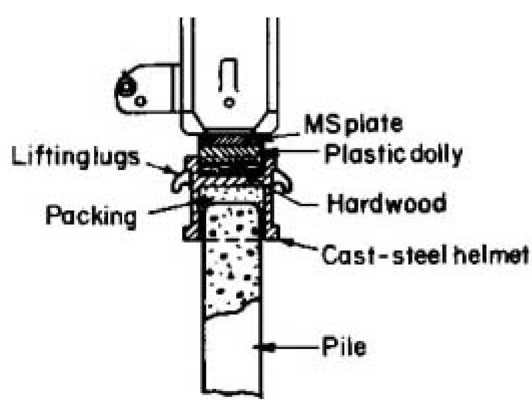

Figure G-55: Driving Helmet and Pile Cushion Installed on a Pile

G602.05 Leads. Leads are used to correctly position a pile and hold it in place during driving. A set of leads typically consists of a three-sided steel lattice similar to a crane boom. The fourth side of the leads is open to allow the pile to be positioned in the leads. The leads also have a set of rails that the pile hammer is positioned on. The pile hammer rides on the rails. The pile hammer can be raised to allow the pile to be positioned, and will descend on the rails as the pile is driven into the ground. Leads can be positioned vertically, or they can be positioned on an angle to drive batter piles.

Subsection 619.05 of the Specifications states that either fixed or swing leads may be used. Fixed leads are attached to the crane or driving platform at both the top and bottom of the leads. This ensures proper positioning of the pile during driving. Swing leads are only attached to the crane or driving platform at the boom. This allows the bottom of the leads to be positioned farther from the crane than fixed leads can be positioned. The disadvantage of swing leads is that it is more difficult to position the leads and maintain vertical alignment during driving. Figure G-56 shows a typical set of fixed leads.

Figure G-56: Fixed Leads

G602.05 Water Jets. Water jets are nozzles attached to the base of a pile during driving. Water jets are used when driving a pile into sand or fine gravel. The jets agitate the soil at the base of the pile, reducing the friction force that resists driving. When jets are used to drive a pile, the last 3' (meter) of driving must be done without the use of the jets. This is done to ensure sufficient resistance when the pile reaches its final depth.

Water jets cannot be used on a Project unless approved by the Engineer or permitted in the Contract. Subsection 619.07 of the Specifications states the requirements for water jets when their use is permitted.

G602.06 Pile Hammers – Manufacturers' Specifications. The following tables summarize the manufacturers' specifications for pneumatic and diesel hammers. These tables may be used as a quick reference when checking the Contractor's equipment.

Table G-3: Pneumatic Pile Hammers - Manufacturers' Specifications

Rated Energy (Ft.-Lbs.)	Manufacturer	Model	Type[1]	Style[2]	BPM	Weight of Hammer (Lbs.)	Total Weight (lbs)	Hammer Length (Ft-In)
1800000	Vulcan	6300	S	O	42	300000	575000	30'0"
1582220	Menck	MRBS12000	S	O	36	275600	540100	71'9"
1500000	Conmaco	2500E6	S	O	36	249122	429900	33'0"
1200000	Vulcan	6200	S	O	36	200000	438218	30'1/2"
1200000	Conmaco	2000E6	S	O	40	200000	490000	35'6"
1050000	Conmaco	1750E6	S	O	40	175000	465000	35'6"
900000	Vulcan	6150	S	O	41	150000	275000	35'3"
868000	Menck	MRBS 8000	S	O	36	176365	330695	30'10"
750000	Conmaco	1500E5	S	O	42	150000	283000	30'6"
750000	Vulcan	5150	S	O	46	150000	275000	26'3.5"
510000	Conmaco	850E6	S	O	40	85000	173600	25'2"
500000	Vulcan	5100	S	O	48	100000	219000	27'4"
499070	Menck	MRBS 4600	S	O	42	101410	176371	27'5"
350000	Conmaco	700E5	S	O	43	70000	152000	23'2"
325480	Menck	MRBS 3000	S	O	42	66100	106000	25'0"
300000	Vulcan	3100	S	O	60	100000	195500	23'3"
300000	Vulcan	560	S	O	47	62500	134060	23'0"
225000	Conmaco	450E5	S	O	45	45000	103000	23'3"
204500	Vulcan	540	S	O	48	40900	102980	22'7"
189850	Menck	MRBS-1800	S	O	42	38600	64600	22'5"
180000	Vulcan	360	S	O	62	60000	124830	19'0"
175000	Vulcan	535	S	O	37	35000	61000	22'4"
150000	Conmaco	300E5	S	O	40	30000	58400	20'10"
150000	Vulcan	530	S	O	42	30000	57860	20'5"
150000	Raymond	60X	S	O	60	60000	85000	22'7"
120000	Vulcan	340	S	O	60	40000	98180	18'7"
100000	Vulcan	520	S	O	42	20000	47680	20'5"
100000	Conmaco	200E5	S	O	46	20000	48000	19'1"
100000	Raymond	40X	S	O	64	40000	62000	19'1"
93340	Menck	MRBS 850	S	O	45	19000	30400	19'8"
90000	Vulcan	030	S	O	54	30000	53470	16'4"
90000	Conmaco	300	S	O	52	30000	55390	16'10"
81250	Raymond	8/0	S	O	40	25000	34000	19'4"
75000	Raymond	30X	S	O	70	30000	52000	19'1"

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Rated Energy (Ft.-Lbs.)	Manufacturer	Model	Type[1]	Style[2]	BPM	Weight of Hammer (Lbs.)	Total Weight (lbs)	Hammer Length (Ft-In)
62500	Conmaco	125E5	S	O	41	12500	22000	18'0"
60000	Conmaco	200	S	O	55	20000	44560	15'0"
60000	Vulcan	512	S	O	41	12000	23480	18'5"
60000	MKT	S-20	S	C	60	20000	38990	15'5"
60000	Vulcan	020	S	O	59	20000	41670	14'8"
57500	Conmaco	115E5	S	O	42	11500	21000	17'9"
56875	Raymond	5/0	S	O	44	17500	26450	16'9"
50000	Vulcan	510	S	O	41	10000	21480	18'5"
50000	Conmaco	100E5	S	O	47	10000	19500	17'9"
50000	Vulcan	200-C	DF	O	95	20000	39000	13'11"
48750	Conmaco	160	S	O	50	16250	33200	13'10"
48750	Vulcan	016	S	O	58	16250	30250	13'11"
48750	Raymond	4/0	S	O	46	15000	23800	16'1"
48750	Raymond	150-C	DF	O	95-105	15000	32500	15'9"
44000	MKT	MS-500	S	O	40-50	11000	15500	15'1"
42000	Conmaco	140	S	O	55	14000	30750	13'10"
42000	Vulcan	014	S	O	59	14000	27500	13'11"
40600	Raymond	3/0	S	O	50	12500	21000	15'7"
40000	Conmaco	80E5	S	O	47	8000	17500	17'9"
40000	Vulcan	508	S	O	41	8000	19480	18'5"
37500	MKT	S-14	S	C	60	14000	31700	13'7"
37375	Conmaco	115	S	O	52	11500	20830	14'2"
36000	Vulcan	140-C	DF	O	101	14000	27984	12'3"
32885	Vulcan	100-C	DF	O	103	10000	22200	14'0"
32500	Conmaco	100	S	O	55	10000	19280	14'2"
32500	Conmaco	65E5	S	O	50	6500	12500	16'10"
32500	Vulcan	506	S	O	46	6500	13025	17'5"
32500	Raymond	2/0	S	O	50	10000	18550	15'0"
32500	Vulcan	010	S	C	50	10000	18780	15'0"
32500	MKT	S-10	S	O	55	10000	22380	4'3.5"
30800	MKT	MS-350	S	O	40-50	7716	10500	15'1"
26000	Conmaco	80	S	O	56	8000	17280	14'2"
26000	Vulcan	85-C	DF	O	111	8525	19020	12'7"
26000	Vulcan	08	S	O	50	8000	16750	14'10"
26000	MKT	S-8	S	C	55	8000	18300	14'4"
25000	Conmaco	50E5	S	O	48	5000	11000	16'10"

Rated Energy (Ft.-Lbs.)	Manufacturer	Model	Type[1]	Style[2]	BPM	Weight of Hammer (Lbs.)	Total Weight (lbs)	Hammer Length (Ft-In)
25000	Vulcan	505	S	O	46	5000	11800	17'5"
24450	Vulcan	80-C	DF	O	109	8000	17885	12'7"
24450	Raymond	80-C	DF	O	95-105	8000	17885	12'2"
24375	Raymond	0	S	O	50	7500	16000	15'0"
24375	Vulcan	0	S	O	50	7500	16250	15'0"
24000	MKT	C-826	C	C	85-95	8000	17750	12'2"
19500	Conmaco	65E3	S	O	61	6500	12100	12'10"
19500	Raymond	65-C	DF	O	110	6500	14675	11'8"
19500	Raymond	1-S	S	O	58	6500	12500	12'9"
19500	Vulcan	06	S	O	60	6500	11200	12'9"
19200	Vulcan	65-C	DF	O	117	6500	14886	12'1"
19150	MKT	11B3	D	C	95	5000	14000	11'2"
16250	MKT	S-5	S	C	60	5000	12460	13'3"
16000	MKT	C-5(STM)	D	C	100-110	5000	11880	-
15100	Vulcan	50C	DF	O	117	5000	11782	11'0"
15000	Conmaco	50E3	S	O	64	5000	10600	12'10"
15000	Vulcan	1	S	O	60	5000	9700	12'9"
15000	Raymond	1	S	O	60	5000	11000	12'9"
14200	MKT	C-5(AIR)	C	C	100-110	5000	11880	8'9"
13100	MKT	10B3	D	C	105	3000	10850	9'2"
8750	BSP	900	D	C	145	1600	7000	7'10"
8750	MKT	9B3	D	C	145	1600	7000	8'4"
7260	Vulcan	30-C	DF	O	133	3000	7036	8'11"
7260	Vulcan	2	S	O	70	3000	6700	11'7"
4700	BSP	700N	D	C	225	860	6614	7'5"
4150	MKT	# 7	D	C	225	800	5000	6'1"
4000	Vulcan	DGH-900	DF	C	238	900	5000	6'9"
3000	BSP	600N	D	C	250	510	4850	7'2"
2500	MKT	# 6	D	C	275	400	2900	5'3"
1200	BSP	500N	D	C	330	200	2425	5'11"
1000	MKT	# 5	D	C	300	200	1500	4'7"
386	Vulcan	DGH-100D	DF	C	303	100	786	4'2"
350	BSP	300	D	C	68	66	683	4'10"
160	BSP	200	D	C	48	44	353	2'9"

Notes: 1. Type - S = Single-acting; D = Double-acting; C = Compound; DF = Differential
2. Style - O = Open; C = Closed

Table G-3M: Pneumatic Pile Hammers – Manufacturers' Specifications

Rated Energy (kJ)	Manufacturer	Model	Type[1]	Style[2]	Blows per Minute	Weight of Hammer (metric tons)	Total Weight (metric tons)	Hammer Length (m)
2440.47	Vulcan	6300	S	O	42	136	261	9.14
2145.20	Menck	MRBS12000	S	O	36	125	245	10.90
2033.73	Conmaco	2500E6	S	O	36	113	195	10.06
1626.98	Vulcan	6200	S	O	36	90.7	199	9.16
1626.98	Conmaco	2000E6	S	O	40	90.7	222	10.82
1423.61	Conmaco	1750E6	S	O	40	79.4	211	10.82
1220.24	Vulcan	6150	S	O	41	68.0	125	10.74
1176.80	Menck	MRBS8000	S	O	38	80.0	150	9.40
1016.86	Conmaco	1500E5	S	O	42	68.0	128	9.30
1016.86	Vulcan	5150	S	O	46	68.0	125	8.01
691.47	Conmaco	850E6	S	O	40	38.6	79	7.67
677.91	Vulcan	5100	S	O	48	45.4	89	8.33
676.65	Menck	MRBS4600	S	O	42	46.0	80	8.36
474.54	Conmaco	700E5	S	O	43	31.8	69	7.06
441.29	Menck	MRBS3000	S	O	42	30.0	49	7.62
406.75	Vulcan	3100	S	O	60	45.4	89	7.09
406.75	Vulcan	560	S	O	47	28.3	61	7.01
305.06	Conmaco	450E5	S	O	45	20.4	47	7.09
271.16	Vulcan	540	S	O	48	18.6	47	6.88
257.40	Menck	MRBS1800	S	O	44	17.5	29	6.83
244.05	Vulcan	360	S	O	62	27.2	57	5.79
237.27	Vulcan	535	S	O	37	15.9	28	6.81
203.37	Conmaco	300E5	S	O	40	13.6	26	6.35
203.37	Vulcan	530	S	O	42	13.6	26	6.22
203.37	Raymond	60X	S	O	60	27.2	39	6.88
162.70	Vulcan	340	S	O	60	18.1	45	5.66
135.58	Vulcan	520	S	O	42	9.1	22	6.22
135.58	Conmaco	200E5	S	O	46	9.1	22	5.82
135.58	Raymond	40X	S	O	64	18.1	28	5.82
126.55	Menck	MRBS850	S	O	45	8.6	13	5.99
122.02	Vulcan	030	S	O	54	13.6	24	4.98
122.02	Conmaco	300	S	O	52	13.6	25	5.13
110.16	Raymond	8/0	S	O	40	11.3	15	5.89
101.69	Raymond	30X	S	O	70	13.6	24	5.82
84.74	Conmaco	125E5	S	O	41	5.7	10	5.49
81.35	Conmaco	200	S	O	55	9.1	20	4.57

Rated Energy (kJ)	Manufacturer	Model	Type[1]	Style[2]	Blows per Minute	Weight of Hammer (metric tons)	Total Weight (metric tons)	Hammer Length (m)
81.35	Vulcan	512	S	O	41	5.4	11	5.61
81.35	MKT	S-20	S	C	60	9.1	18	4.70
81.35	Vulcan	020	S	O	59	9.1	19	4.47
77.96	Conmaco	115E5	S	O	42	9.1	10	5.41
77.11	Raymond	5/0	S	O	44	5.2	12	5.11
67.79	Vulcan	510	S	O	41	7.9	10	5.61
67.79	Conmaco	100E5	S	O	47	4.5	9	5.41
67.79	Vulcan	200-C	DF	O	95	4.5	18	4.24
66.10	Conmaco	160	S	O	50	9.1	15	4.22
66.10	Vulcan	016	S	O	58	7.4	14	4.24
66.10	Raymond	4/0	S	O	46	7.4	11	4.90
66.10	Raymond	150-C	DF	O	95	6.8	15	4.80
61.28	Menck	MRBS500	S	O	48	6.8	6.9	5.08
59.66	MKT	MS-500	S	O	40	5.0	7.0	4.60
56.94	Conmaco	140	S	O	55	5.0	14	4.22
56.94	Vulcan	014	S	O	59	6.4	12	4.17
55.05	Raymond	3/0	S	O	50	6.4	10	4.75
54.23	Conmaco	80E5	S	O	47	5.7	7.9	5.41
54.23	Vulcan	508	S	O	41	3.6	8.8	5.61
50.84	MKT	S-14	S	C	60	3.6	14	4.14
50.67	Conmaco	115	S	O	52	6.4	9.4	4.32
48.81	Vulcan	140-C	DF	O	101	5.2	13	3.73
44.59	Vulcan	100-C	DF	O	103	6.4	10	4.27
44.06	Conmaco	100	S	O	55	4.5	8.7	4.32
44.06	Conmaco	65E5	S	O	50	4.5	5.7	5.13
44.06	Vulcan	506	S	O	46	2.9	5.9	5.31
44.06	Raymond	2/0	S	O	50	2.9	8.4	4.57
44.06	Vulcan	010	S	C	50	4.5	8.5	4.57
44.06	MKT	S-10	S	O	55	4.5	10	4.29
41.76	MKT	MS-350	S	O	40	4.5	4.8	4.60
35.25	Conmaco	80	S	O	56	3.5	7.8	4.32
35.25	Vulcan	85-C	DF	O	111	3.6	8.6	3.84
35.25	Vulcan	08	S	O	50	3.9	7.6	4.52
35.25	MKT	S-8	S	C	55	3.6	8.3	4.37
33.90	Conmaco	50E5	S	O	48	3.6	5.0	5.13
33.90	Vulcan	505	S	O	46	2.3	5.4	5.31
33.15	Vulcan	80-C	DF	O	109	2.3	8.1	3.84
33.15	Raymond	80-C	DF	O	95	3.6	8.1	3.71

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Rated Energy (kJ)	Manufacturer	Model	Type[1]	Style[2]	Blows per Minute	Weight of Hammer (metric tons)	Total Weight (metric tons)	Hammer Length (m)
33.05	Raymond	0	S	O	50	3.6	7.3	4.57
33.05	Vulcan	0	S	O	50	3.4	7.4	4.57
32.54	MKT	C-826	C	C	85	3.4	8.1	3.71
26.44	Conmaco	65E3	S	O	61	3.6	5.5	3.91
26.44	Raymond	65-C	DF	O	110	2.9	6.7	3.56
26.44	Raymond	1-S	S	O	58	2.9	5.7	3.89
26.44	Vulcan	06	S	O	60	2.9	5.1	3.96
26.03	Vulcan	65-C	DF	O	117	2.9	6.8	3.68
25.96	MKT	11B3	D	C	95	2.3	6.4	3.40
22.03	MKT	S-5	S	C	60	2.3	5.7	4.04
21.69	MKT	C-5(STM)	D	C	100	2.3	5.4	0.00
20.47	Vulcan	50-C	DF	O	117	2.3	5.3	3.35
20.34	Conmaco	50-E3	S	O	64	2.3	4.8	3.91
20.34	Vulcan	1	S	O	60	2.3	4.4	3.9
20.34	Raymond	1	S	O	60	2.3	5.0	3.89
19.25	MKT	C-5(AIR)	C	C	100	2.3	5.4	2.67
17.76	MKT	10B3	D	C	105	1.4	4.9	2.79
11.86	BSP	900	D	C	145	0.73	3.2	2.39
11.86	MKT	9B3	D	C	145	0.73	3.2	2.54
9.84	Vulcan	30-C	DF	O	133	1.4	3.2	2.72
9.84	Vulcan	2	S	O	70	1.4	3.0	3.53
6.37	BSP	700N	D	C	225	0.39	3.0	2.26
5.63	MKT	7	D	C	225	0.36	2.3	1.85
5.42	Vulcan	DGH-900	DF	C	238	0.41	2.3	2.06
4.07	BSP	600N	D	C	250	0.23	2.2	2.18
3.39	MKT	6	D	C	275	0.18	1.3	1.60
1.63	BSP	500N	D	C	330	0.09	1.1	1.80
1.36	MKT	5	D	C	300	0.09	0.7	1.40
0.52	Vulcan	DGH-100D	DF	C	303	0.05	0.36	1.27
0.47	BSP	300	D	C	68	0.03	0.31	1.47
0.22	BSP	200	D	C	48	0.02	0.16	0.84

Notes: 1. Type – S = Single-acting; D = Double-acting; C = Compound; DF = Differential
2. Style – O = Open; C = Closed

Table G-4: Diesel Pile Hammers – Manufacturers' Specifications

Energy Range (Ft. Lb.) From	To	Manufacturer	Model	Type[1]	Blows per Minute	Weight of Hammer (Lbs.)	Total Weight (Lbs.)	Hammer Length (Ft.-In.)
750000	384000	Delmag	D350	S	36-50	77162	165347	34'10"
300000	157443	Delmag	D100-13	S	34-45	23612	43703	20'4"
225000	126190	Delmag	D80-23	S	36-45	19500	36085	20'4"
165000	78960	Delmag	D62-22	S	36-50	14600	26173	19'4"
149600	88000	Mitsubishi	MH80B	S	42-60	17600	43600	19'6"
141000	63360	Mitsubishi	MB70	S	38-60	15840	46000	19'6"
135100	79500	Mitsubishi	MH72B	S	38-60	15900	44000	19'6"
127500	90000	MKT	DE-150/110	S	40-50	15000	32150	19'10"
120000	48000	ICE	120S	S	38-55	12000	23800	19'10"
117000	62500	Delmag	D55	S	36-47	12128	26300	17'9"
107770	52250	Delmag	D46-32	S	37-53	10143	19580	17'4"
105800	41400	Berminghammer	B-5505	S	36-60	9200	21400	21'8"
100000	40000	ICE	200S	S	53-70	20000	33.600	17'
100000	40000	ICE	100S	S	38-55	10000	18800	19'
	90000	MKT	DE-150/110C	S	40-50	15000	32150	19'11"
92752	39000	Kobe	K45	S	39-60	9920	25300	18'6"
90000	36000	ICE	90S	S	38-55	9000	16800	17'3"
87400	34200	Berminghammer	B-5005	S	35-60	7600	19800	21'8"
87000	43000	Delmag	D44	S	37-56	9500	22300	15'11"
85400	50200	Mitsubishi	MH45	S	42-60	10500	24600	17'11"
84000	37840	Mitsubishi	M43	S	40-80	9460	22660	16'3"
83880	40900	Delmag	D36-32	S	36-53	7938	16515	17'4"'
80000	32000	ICE	80S	S	38-55	8000	15400	18'11"
79500		IHI	J44	S	42-70	9720	21500	14'10"
75900	29700	Berminghammer	B-4505	S	36-60	6600	16100	19'1"
73000	40153	FEC	3400	S	40-60	7495	14550	16'0"
72182	31700	Kobe	K35	S	39-60	7720	19100	17'8"
70000	28000	ICE	70S	S	38-55	7000	14100	16'8"
70000	36100	ICE	1070	D	64-68	10000	32500	17'10"
70000	42000	MKT	DE-70/5OC	S	40-50	7000	16285	17'11"
69898	35383	Delmag	D30-32	S	36-52	6615	12855	17'3"
65600	38600	Mitsubishi	MH35	S	42-60	7720	18500	17'3"
64600	29040	Mitsubishi	M33	S	40-60	7260	16940	13'2"
63500		IHI	J35	S	72-70	7730	16900	14'6"
63000	34650	F.E.C.	3000	S	40-60	6600	13200	17'
60000	26000	ICE	60S	S	41-59	7000	13900	17'
58248	29486	Delmag	D25-32	S	37-52	5513	11752	17'3"
57877		Vulcan	V25-1	S	42	5513	11752	16'4"
57500	22500	Berminghammer	B-4005	S	36-60	5000	14500	19'1"
54250	23800	Delmag	D30	S	39-60	6615	12300	14'3"
54000	22500	Berminghammer	B-400	S	38-60	5000	16000	19'4"
50000	30000	MKT	DE-70/50C	S	40-50	5000	14285	17'11"
50000	27500	F.E.C.	2500	S	40-60	5500	12100	17'
50000	25100	ICE	660	D	84-88	7564	24480	17'4"
48500	24500	Delmag	D22-23	S	38-52	4850	11400	17'2"

Energy Range (Ft. Lb.) From	To	Manufacturer	Model	Type[1]	Blows per Minute	Weight of Hammer (Lbs.)	Total Weight (Lbs.)	Hammer Length (Ft.-In.)
46900	27550	Mitsubishi	MH25	S	42-60	5510	13200	16'8"
46000	18000	Berminghammer	B-3505	S	36-60	4000	10500	18'6"
45000	20240	Mitsubishi	M23	S	42-60	5060	11220	14'1"
44800		BSP	DE50C	S	42-54	4980	10300	14'4"
42800	20500	Delmag	D19-32	S	37-53	4190	9650	15'6"
42500	30000	MKT	DA-55C	S	40-50	5000	17635	17'4"
42000	16000	ICE	42S	S	37-55	4088	7610	16'1"
40500	16875	Berminghammer	B-300	S	38-60	3750	9892	18'4"
40200	18871	Delmag	D16-32	S	36-52	3528	7386	15'6"
40000	25400	ICE	640	D	74-77	6000	14460	15'7"
40000	24000	MKT	DE-33/30/20C	S	40-50	4000	9400	15'11"
40000	16000	ICE	40S	S	38-55	4000	7500	15'9"
39700		Delmag	D22	S	42-60	4850	11200	14'2"
39100	12000	IHI	J22	S	42-70	4850	10800	14'
39070		Vulcan	V18	S	42	4000	8600	4'5"
38200	31200	MKT	DA-55C	D	78-82	5000	17635	17'4"
34500	12000	Berminghammer	B-2505	S	36-60	3086	11023	18'1"
34000	24000	MKT	DA-45C	S	40-50	3970	14110	15'1"
33000	19800	MKT	DE-33/30/20C	S	40-50	3300	8700	5'11"
31200	15660	Delmag	D12-32	S	36-52	2820	5730	15'6"
30700	18500	MKT	DA-45C	D	78-82	3968	14110	15'1"
30000	17000	ICE	520-30	D	80-84	5070	13448	13'7"
29400	13500	Berminghammer	B-225	S	39-60	3000	9142	18'4"
28100	16550	Mitsubishi	MH15	S	42-60	3310	8400	16'1"
28000	16800	MKT	DE-33/30/20C	S	40-50	2800	8200	15'11"
27100	14900	F.E.C.	1500	S	40-60	3300	7225	15'8"
27128		Vulcan	V12	S	42	3300	5953	14'5"
27190		Delmag	D15	S	40-60	3300	6615	13"11"
27000		BSP	DE30C	S	42-54	3000	7600	14'2"
26300	17701	ICE	520-26	D	80-84	5070	12566	13'6"
26000	11800	Mitsubishi	M14S	S	42-60	2970	7260	13'6"
25428	13200	KOBE	K13	S	40-60	2870	7800	16'8"
21000	15600	MKT	DA-35C	D	78-82	2800	11750	17'0"
23000		Berminghammer	B-23	D	82	2800	9940	20'10"
22500	12375	F.E.C.	1200	S	40-60	2750	6540	15'6"
22500		Delmag	D12	S	42-60	2750	6050	13'11"
22500	9000	ICE	422	D	76-82	4000	9750	13'11"
22500	9000	ICE	30S	S	44-67	3000	6250	12'4"
23800	16800	MKT	DA-35C	S	40-50	2800	11750	17'0"
20000	12000	MKT	DE-33/30/20C	S	40-50	2000	7400	15'11"
18100	7700	ICE	440	D	88-92	4000	9840	13'6"
18000	9434	Delmag	D8-22	S	38-52	1762	4000	15'5"
18000	7500	Linkbelt	312	D	100-105	3857	10375	10'9"
20400	9000	Berminghammer	B-200	S	38-58	2000	6940	15'
10500	6300	Delmag	D6-32	S	39-52	1322	3570	12'6"
9350	6600	MKT	DA-15C	S	40-50	1100	5700	13'11"
9150		Delmag	D5	S	42-60	1100	2730	12'6"

Energy Range (Ft. Lb.) From	To	Manufacturer	Model	Type[1]	Blows per Minute	Weight of Hammer (Lbs.)	Total Weight (Lbs.)	Hammer Length (Ft.-In.)
8800	6600	MKT	DE-10	S	40-50	1100	3518	12'2"
8200	6600	MKT	DA-15C	D	86-92	1100	5700	13'11"
8100	4060	ICE	180	D	90-95	1725	4645	11'3"
3630	1125	Delmag	D4	S	50-60	836	1360	7'9"
1815	868	Delmag	D2	S	60-70	484	792	6'9"

Note: 1. Type – S = Single-acting; D = Double-acting

Table G-4M: Diesel Pile Hammers – Manufacturers' Specifications

Energy Range (kJ) From	Energy Range (kJ) To	Manufacturer	Model	Type[1]	Blows per Minute	Weight of Hammer (metric tons)	Total Weight (metric tons)	Hammer Length (m)
1016.86	520.63	Delmag	D350	S	36-50	35.0	75.0	10.62
406.75	213.87	Delmag	D100-13	S	34-45	10.7	20.6	6.20
305.06	171.09	Delmag	D80-23	S	36-45	8.8	17.1	6.20
223.71	107.06	Delmag	D62-22	S	36-50	6.6	12.3	5.94
202.83	119.31	Mitsubishi	MH80B	S	42-60	8.0	19.8	5.94
191.17	85.90	Mitsubishi	MB70	S	38-60	7.2	20.9	5.94
183.17	107.79	Mitsubishi	MH72B	S	38-60	7.2	20.0	5.94
172.87	122.02	MKT	DE150/110	S	40-50	6.8	13.4	6.05
162.70	65.08	ICE	120S	S	38-55	5.4	10.8	6.02
158.63	84.74	Delmag	D55	S	36-47	5.5	11.9	5.41
145.30	70.86	Delmag	D46-32	S	37-53	4.6	8.9	5.28
143.45	49.89	Berminghammer	B-5505	S	36-60	4.2	10.9	6.71
135.58	54.23	ICE	200S	S	53-70	9.1	15.2	5.18
135.58	54.23	ICE	100S	S	38-55	4.5	8.5	5.77
126.77	89.48	MKT	DE-150/110	S	40-50	5.0	11.1	5.44
125.75	52.88	Kobe	K45	S	39-60	4.5	11.5	5.64
122.02	48.81	ICE	90S	S	38-55	4.1	7.6	5.26
118.50	41.22	Berminghammer	B-5005	S	36-60	3.4	10.2	6.71
117.96	58.98	Delmag	D44	S	37-56	4.3	10.1	4.83
115.79	68.06	Mitsubishi	MH45	S	42-60	4.8	11.2	4.60
113.89	51.30	Mitsubishi	M43	S	40-60	4.3	10.3	4.95
113.73	55.45	Delmag	D36-32	S	36-53	3.6	7.9	5.28
108.47	43.39	ICE	80S	S	38-55	3.6	7.0	5.77
107.79		IHI	J44	S	42-70	4.4	9.8	4.52
102.91	35.93	Berminghammer	B-4505	S	36-60	3.0	7.3	5.66
98.97	54.44	FEC	3400	S	40-60	3.4	6.6	4.88
97.87	42.98	Kobe	K35	S	39-60	3.5	8.7	5.38
94.91	37.96	ICE	70S	S	38-55	3.2	6.4	5.08
94.91	48.95	ICE	1070	D	64-68	4.5	9.8	5.44
94.91	56.94	MKT	DE70/50C	S	40-50	3.2	6.7	5.46
94.77	47.97	Delmag	D30-32	S	36-52	3.0	6.0	5.26
88.94	52.33	Mitsubishi	MH35	S	42-60	3.5	8.4	5.26
87.59	39.37	Mitsubishi	M33	S	40-60	3.3	7.7	4.01
86.09		IHI	J35	S	72-70	3.5	7.7	4.42
85.42	46.98	FEC	3000	S	40-60	3.0	6.0	4.72
81.35	35.25	ICE	60S	S	41-59	3.2	6.3	5.16
78.98	39.97	Delmag	D25-32	S	37-52	2.5	5.5	5.26

Energy Range (kJ)					Blows per	Weight of Hammer	Total Weight	Hammer
From	To	Manufacturer	Model	Type[1]	Minute	(metric tons)	(metric tons)	Length (m)
78.47		Vulcan	V25-1	S	42	2.5	5.5	4.98
77.96	27.12	Berminghammer	B-4005	S	36-60	2.3	6.5	5.66
73.55	32.27	Delmag	D30	S	39-60	3.0	5.6	4.34
72.88	27.25	Berminghammer	B-400	S	37-60	2.3	6.8	4.52
69.49	31.86	Kobe	K25	S	39-60	2.5	6.0	5.33
67.79	40.67	MKT	DE70-50C	S	40-50	2.3	5.8	5.46
67.79	37.28	FEC	2500	S	40-60	2.5	5.5	4.72
67.79	34.03	ICE	660	D	84-88	3.4	11.1	5.28
65.76	33.22	Delmag	D22-23	S	38-52	2.2	5.2	5.23
63.59	37.35	Mitsubishi	MH25	S	42-60	2.5	6.0	5.08
62.37	21.69	Berminghammer	B-3505	S	36-60	1.8	5.4	5.51
61.01	27.44	Mitsubishi	M23	S	42-60	2.3	5.1	4.29
60.74		BSP	DE50C	S	42-54	2.3	4.7	4.37
58.03	27.85	Delmag	D19-32	S	37-53	1.9	3.5	4.72
57.62	40.67	MKT	DA-55C	S	40-50	2.3	7.7	5.28
56.94	21.69	ICE	42S	S	37-55	1.9	3.5	4.90
54.64	20.34	Berminghammer	B-300	S	37-60	1.7	4.3	4.27
54.50	25.58	Delmag	D16-32	S	36-52	1.6	3.4	4.72
54.23	34.44	ICE	640	S	74-77	2.7	6.6	4.75
54.23	32.54	MKT	DE-33/30/20C	S	40-50	1.8	4.3	4.85
54.23	21.69	ICE	40S	S	38-55	1.8	3.4	4.80
53.83		Delmag	D22	S	42-60	2.2	5.1	4.32
53.01	16.27	IHI	J22	S	42-70	2.2	4.9	4.27
52.97		Vulcan	V18	S	42	1.8	3.9	4.39
51.79	42.30	MKT	DA-55C	D	78-82	2.3	7.7	5.28
46.78	16.27	Berminghammer	B-2505	S	36-60	1.4	5.0	5.51
46.10	32.54	MKT	DA-45C	S	40-50	1.8	6.4	4.60
44.74	26.85	MKT	DE-33/30/20C	S	40-50	1.5	3.9	4.85
42.46	21.23	Delmag	D12-32	S	36-52	1.3	2.8	4.72
41.62	25.08	MKT	DA-45C	D	78-82	1.8	6.4	4.60
40.67	23.05	ICE	520-30	D	80-84	2.3	6.1	4.14
39.66	16.27	Berminghammer	B-225	S	39-60	1.4	4.0	4.27
38.10	22.44	Mitsubishi	MH15	S	42-60	1.5	3.8	4.90
37.96	22.78	MKT	DE33/30/20C	S	40-50	1.3	3.7	4.85
36.74	20.20	FEC	1500	S	40-60	1.5	3.3	4.32
36.78		Vulcan	V12	S	42	1.3	2.7	4.39
36.74		Delmag	D15	S	40-60	1.5	3.0	4.24
36.61		BSP	DE30C	S	42-54	1.4	3.4	4.32

Energy Range (kJ)								
From	To	Manufacturer	Model	Type[1]	Blows per Minute	Weight of Hammer (metric tons)	Total Weight (metric tons)	Hammer Length (m)
35.66	24.00	ICE	520-26	D	80-84	2.3	5.7	4.11
35.25	16.00	Mitsubishi	M14S	S	42-60	1.3	3.3	4.11
34.48	17.90	Kobe	K13	S	40-60	1.3	3.5	5.08
32.27	22.78	MKT	DA-35C	S	40-50	1.3	4.9	5.18
31.18		Berminghammer	B-23	D	80	1.3	4.5	4.88
30.51	16.78	FEC	1200	D	40-60	1.2	3.0	4.27
30.51		Delmag	D12	S	42-60	1.2	2.7	4.24
30.51	12.20	ICE	422	D	76-82	1.8	4.4	4.24
30.51	12.20	ICE	30S	S	44-67	1.4	2.8	3.76
28.47	21.15	MKT	DA-35C	D	78-82	1.3	4.9	5.18
27.12	16.27	MKT	DE33/30/20C	S	40-50	0.9	3.4	4.85
24.54	10.44	ICE	440	D	88-92	1.8	4.5	4.11
24.40	12.79	Delmag	D8-22	S	38-52	0.8	1.9	4.70
24.40	10.17	ICE	312	D	100-105	1.7	4.7	3.28
24.40	11.66	Berminghammer	B-200	S	39-58	0.9	3.1	4.19
14.24	8.54	Delmag	D6-32	S	39-52	0.6	1.7	3.81
12.68	8.95	MKT	DA-15C	S	40-50	0.5	2.2	4.24
12.34		Delmag	D5	S	42-60	0.5	1.2	3.81
11.93		MKT	DE10	S	40-50	0.5	1.4	3.71
11.12	8.95	MKT	DA-15C	D	86-92	0.5	2.2	4.24
10.98	5.50	ICE	180	D	90-95	0.8	2.1	3.43
4.92	2.20	Delmag	D4	S	50-60	0.4	0.6	2.36
2.46	1.18	Delmag	D2	S	60-70	0.2	0.4	2.06

Note: 1. Type – S = Single-acting; D = Double-acting

G602.07 Pile Driving Equipment Manufacturers. The following is a partial list of companies that manufacture pile driving equipment. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	Location	Phone Number
Berminghammer	Hamilton, Ontario, Canada	905-528-0425
BSP International	Ipswich, England	44-473-8330431
Conmaco	Belle Chase, LA	800-259-7330
Delmag/Pileco	Houston, TX	800-474-5326
FEC Diesel Hammers	Dover, OH	800-321-5539
ICE – International Construction Equipment	Matthews, NC	800-438-9281
IHC (The LB Foster Company)	Pittsburgh, PA	800-255-4500
KOBE (Hercules Machinery Corp.)	Sterling, VA	800-223-8427
Menck (Delmag/Pileco)	Houston, TX	800-474-5326
Mitsubishi (ICE)	Matthews, NC	800-438-9281
MKT	St. Louis, MO	314-388-2254
Raymond (Vulcan Iron Works)	Chattanooga, TN	800-742-6637
Vulcan Iron Works	Chattanooga, TN	800-742-6637

DIVISION G700 – MISCELLANEOUS CONSTRUCTION

SECTION G701 – HYDROSEEDERS

G701.01 General. Hydroseeders are machines designed to spray or broadcast a combination of fertilizer, seeds, water, and mulch over a designated area. These machines are an ideal choice for revegetation and erosion control along roadsides and medians because they enable the operator to evenly distribute seeds over a wide area.

A typical hydroseeding system consists of a tank with agitators, a high volume pump, and a discharge nozzle. The pumping unit is connected to the desired spray nozzle via a flexible hose. The entire system may be mounted on a trailer or directly on the back of a truck, depending on the tank size.

G701.02 Agitation Systems. There are three kinds of agitation systems used in hydro seeders: mechanical, recirculating, and tandem. Mechanically agitated hydroseeders use motorized paddles to rapidly mix seeds, fertilizer, and other additives. When these agitators are activated, the hydroseeder pump is disengaged to prevent seed damage. These machines pump the slurry slow enough to reduce damage caused from abrasive seed and fertilizer grains as they are forced out of the hydroseeder tank. It is important to note that since mechanical agitation systems use belt and clutch mechanisms to control pump and agitator action, they may need to be serviced or replaced more frequently than other systems.

Hydroseeders with recirculating tanks contain nozzles that force slurry toward the tank bottom. The resulting high-pressure turbulence effectively mixes the tank contents. Clutches and belt mechanisms are usually not used in recirculating tanks, which results in fewer moving parts, and thus lower maintenance. However, the high-speed expulsion of slurry may cause abrasion damage to the pumping system over time.

Some manufacturers offer hydroseeders that combine both types of agitation in a single system. Hydroseeders with tandem agitation systems offer greater homogeneity in the broadcast slurry due to the high rate of agitation.

G701.03 Tanks and Mountings. Tank and mounting configurations can also vary. Larger tanks are usually manufactured using steel coated with epoxy to prevent rust. Smaller hydroseeders may be built using plastic tanks. Generally, larger tanks are mounted on platforms welded to the backs of large diesel trucks. Platform mounted hydroseeders feature spray towers that can rotate 360 degrees as well as ground spray hose connections. The operator controls the hydroseeders from the platform, which is surrounded by safety rails. Smaller hydroseeders may be built using plastic or steel tanks and are mounted on wheeled trailers or skids. Figures G-57 through G-59 show the three different kinds of hydroseeder mountings.

Figure G-57: Typical Truck-mounted Hydroseeder

Figure G-58: Trailer-mounted Hydroseeder

Figure G-59: Typical Skid-mounted Hydroseeder

G701.04 The Hydroseeding Process. Before the hydroseeding process can begin, the correct seed mix, lime, mulch, and fertilizer must be chosen to complete the mixture or slurry. Usually, wood fiber or wood cellulose fiber is selected to help prevent the loss of moisture and protect the seeds as they germinate. Once the seeds begin to grow, the wood fiber mulch will decompose and nourish the seeds and soil.

The wood cellulose fiber normally contains a dye that permits visual inspection to ensure even distribution.

Once the slurry components are chosen, they are combined with water and mixed within the hydroseeder tank. After the mixture is agitated, it is ready to be broadcast over the target area. The high volume pump forces the slurry out of the nozzle to the target area. Figure G-60 shows a hydroseeder distributing seed mixture.

Figure G-60: Hydroseeder Distributing Seed Mixture

G701.05 Hydroseeder Manufacturers. The following is a partial list of companies in the United States that manufacture hydroseeders. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Manufacturer	Location	Phone Number
Finn Corporation	Fairfield, OH	800-543-7166
Reinco Inc.	Plainfield, New Jersey	800-526-7687
TGMI, Inc.	Cincinnati, Ohio	800-241-8464

SECTION G702 – TRAFFIC PAINT STRIPERS

G702.01 General. Traffic paint stripers are used to apply traffic control markings to the surface of roadways. This equipment consists of paint applicators (called applicator guns) a pumping system, tanks for paint, and glass beads. Traffic paint stripers may be configured to operate from platforms mounted on trucks; small walk-behind carts; self-propelled ride-on carts; or trailer mounted carts.

During the painting process, the truck- or cart-mounted paint striper moves slowly along the road as the pumping systems force the paint and glass beads through the applicators. Glass beads add reflectivity to the paint stripe. The guns atomize the paint stream and help to distribute the paint evenly on the road surface. All paint application equipment, glass beads, and paint must comply with the Section 748 of the Specifications.

G702.02 Configurations. Truck-mounted paint stripers feature high capacity paint, glass, and thermoplastic tanks. In addition, these stripers have actuators that enable the operator to adjust the line and video guidance systems to aid with spray gun positioning. An enclosed operator cab may be found on the rear of the striper truck with additional truck steering controls. The extra steering column allows the striper operator to make fine adjustments in the position of the truck. These trucks may travel up to 35 mph (60 km/h) while painting.

Smaller paint stripers, including trailer-mounted units, walk-behind carts, and self-propelled carts, provide operators with greater maneuverability in confined areas. Small stripers are especially useful for parking space and driveway marking. Figures G-61 through G-64 show several different traffic paint striper configurations.

Figure G-61: Truck-mounted Traffic Paint Striper

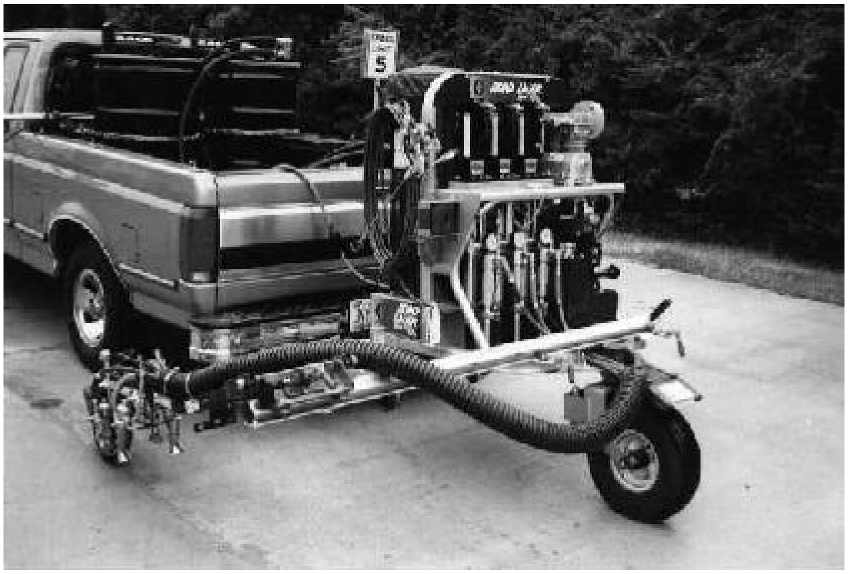

Figure G-62: Trailer-mounted Traffic Paint Striper

Figure G-63: Walk-behind Traffic Paint Striper

Figure G-64: Self-propelled Traffic Paint Striper

G702.03 Application Technology. Paint stripers can be classified according to the paint application system being used. The two kinds of application systems are airless machines and air-atomized spray units.

Air-atomized paint stripers use large compressors and heavy pressure vessels to generate high-pressure air. This air is used to force the paint through the applicator guns. These stripers work better when contractors work on a series of small jobs because the paint will not dry out if left sitting in the tanks. An important drawback to air-atomized spray stripers is that they have a low transfer efficiency. This means that as much as 25 percent of the atomized paint is scattered or over-sprayed and does not reach the road surface.

Airless technology is more useful for large highway striping jobs. This system does not require large compressors and pressure vessels, which allows more space for additional paint and glass beads. Airless stripers use piston pumps to withdraw paint from zero-pressure tanks. This pumping action drives the paint through the applicator guns under high pressure. In addition, airless stripers have a higher transfer efficiency compared to air-atomized stripers. Airless systems are also easier to clean and maintain since they do not have air compressors.

G702.04 Paint Striper Manufacturers. The following is a partial list of companies in the United States that manufacture paint stripers and associated equipment. This list is for reference only. Inclusion or omission of a manufacturer from this list does not imply endorsement by the Department.

Revised: January 2004

Manufacturer	Location	Phone Number
EZ-Liner	Orange City, Iowa	800-373-4016
MRL Equipment Company	Billings, MT	406-245-8710
Pathmark Traffic Products of Texas, Inc.	San Marcos, TX	800-547-0874
Kelly-Creswill Company, Inc.	Xenia, OH	800-372-9221

Revised: January 2004

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